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Coast Guard Mission Data Recorder (MDR) for the 47-FT Motor Lifeboat

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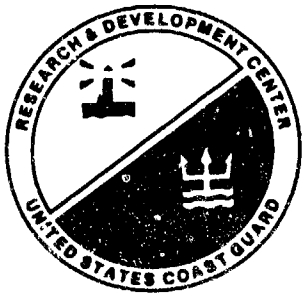

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16. Abstract

A Mission Data Recorder (MDR) was designed and built by the Coast Guard R&D Center to support the Operational Test and Evaluation (OT&E) of the 47-FT Motor Lifeboat (MLB).

The OT&E was under the overall direction of the Motor Lifeboat Replacement Acquisition Project Manager, Commandant (G-AMB).

The purpose of the MDR was to collect both short-term event data and long-term vessel motions data in an autonomous manner. Some significant events have been recorded, including a 137-degree roll event, during which the values of roll, pitch, yaw, engine RPM and rudder angle were recorded.

Testing of five 47-FT MLBs will continue for at least another six months. The MDR will record significant roll events and long-term vertical acceleration data for use in a crew fatigue study.

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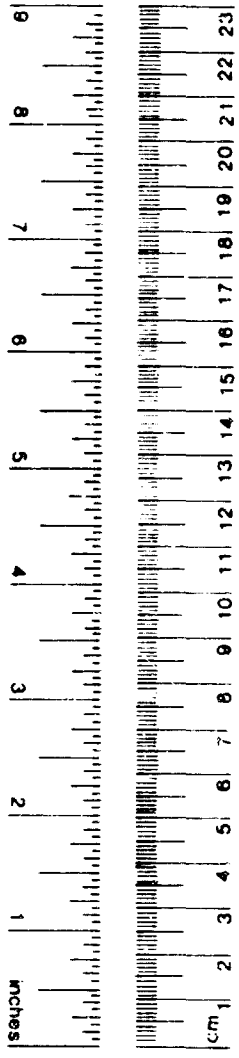
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
in	inches	* 2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	*miles*	1.6	*kilometers*	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (WEIGHT)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	*cubic meters*	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (EXACT)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly)



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (WEIGHT)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	0.125	cups	c
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
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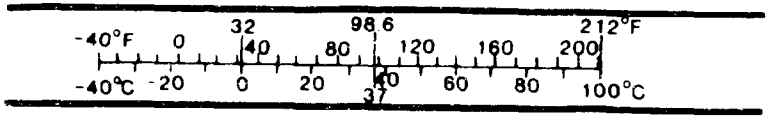
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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ACKNOWLEDGEMENTS

The cooperation of each of the five stations tasked with testing the preproduction 47-FT Motor Lifeboats is gratefully acknowledged. Although a nearly autonomous mission data recorder (MDR) device was developed, some additional responsibility had to be given to each station (on top of their already busy work schedule) to support the MDR data collection. Appreciation is expressed to the sponsor (G-NRS), particularly CDR M. Lewandowski and CDR J. McGuiness, for taking an active interest and providing encouragement to fully develop the MDR. Additionally, appreciation is expressed to Mr. G. Hayward for introducing us to a datalogger that could do the job and for all of his hardware and software contributions. GESAC, Inc. is also acknowledged for their support in developing an animation capability. Acknowledgement is due to LCDR D. E. Milburn who originally conceived many of the ideas for the MDR before his transfer from the R&D Center. Acknowledgement is due to ETC T. Brion and BM2 D. Harding, both members of the MDR installation team. ETC Brion has taken on the responsibility of retrieving MDR data on a routine basis and organizing the voluminous data collected.

EXECUTIVE SUMMARY

A Mission Data Recorder (MDR) was designed and built by the Coast Guard R&D Center to support the Operational Test and Evaluation (OT&E) of the 47-FT Motor Lifeboat (MLB).

The OT&E was conducted by G-NRS to evaluate the effectiveness and suitability of five 47-FT MLBs placed at various stations under operation by normal Coast Guard crews, as opposed to the prototype, which had a special Test Team.

The purpose of the MDR was to collect both short-term motion event data and long-term vessel motions data in an autonomous manner, similar to an aircraft flight data recorder.

Some significant events were recorded during the first six-month OT&E period, including a 137-degree roll by one of the boats. A permanent record of the event and its surrounding time frame was obtained, showing roll, pitch, yaw, engine RPM and rudder angle. On two occasions where severe roll occurred, the engine on the side toward the roll stalled, and was re-started in about one minute. A computer screen animation of the event was also developed, to assist in debriefing and training of the crew.

The MDR also records the LORAN position of the boat every ten minutes. The Coast Guard Electronic Engineering Center's program, "Geographical Display Operations Computer," was used to plot MDR position data. A computer screen chart overlay, showing the boat's positions over a one-month period, was used to produce a chart plot of its operational area.

R&DC will continue to monitor MDR data for an additional six months in FY95 to obtain long-term statistics on vertical accelerations for use in a crew fatigue study. Significant roll events will also be recorded to assist in post-event analysis and crew training.

INTRODUCTION

The 47-FT Motor Lifeboat (MLB) design was developed by the U.S. Coast Guard and Textron Marine Systems. The 47-FT MLB is designed as a heavy weather rescue boat with self-righting capabilities. The self-righting capability of a 47-FT MLB is essential since it can expect to encounter violent motions in the surf with an occasional severe roll or even 360 degree rollover in the course of conducting operations.

The Coast Guard is planning to procure about one hundred of these craft to replace the aging 44-FT MLBs. Prior to full-scale production, five preproduction boats are undergoing an Operational Test & Evaluation (OT&E). The five Coast Guard stations involved with the OT&E are:

Station Cape May, Cape May, NJ	47201
Station Oregon Inlet, Rodanthe, NC	47202
Station Tillamook, Garibaldi, OR	47203
Station Umpqua River, Reedsport, OR	47204
Station Gloucester, Gloucester, MA	47205

Figure 1 illustrates the relative geographic locations of the 47-FT MLBs.

The objective of the OT&E as defined in the OT&E Plan [1] is to evaluate the ***effectiveness*** and ***suitability*** of the Coast Guard 47-FT MLB. The OT&E results will be provided to the Coast Guard Acquisition Review Council (CGARC) to support decision-making policies regarding the decision to go ahead with full production of a 47-FT MLB fleet.

The R&D Center was tasked to develop a Mission Data Recorder (MDR) to autonomously record operating hours, motion environment, operational profile, and capture any significant events such as a boat rollover. The task of developing an MDR, which addresses one of the six OT&E evaluation components [1], is the subject of this report.

BACKGROUND

Concept Development

Prior to the construction of the preproduction boats an extensive Developmental Test & Evaluation (DT&E) was performed on the prototype 47-FT MLB (47200). The R&D Center conducted a variety of technical tests including seakeeping, maneuvering, structural loading, etc., the results of which can be found in the report entitled "Technical Characteristics Verification of the Prototype 47 FT MLB" [2]. The prototype performed exceedingly well in most of the technical areas tested. However, maneuvering problems were identified with the original design of employing large canted rudders. These rudders were very efficient and sometimes tended to induce excessive roll. This phenomena was revealed in

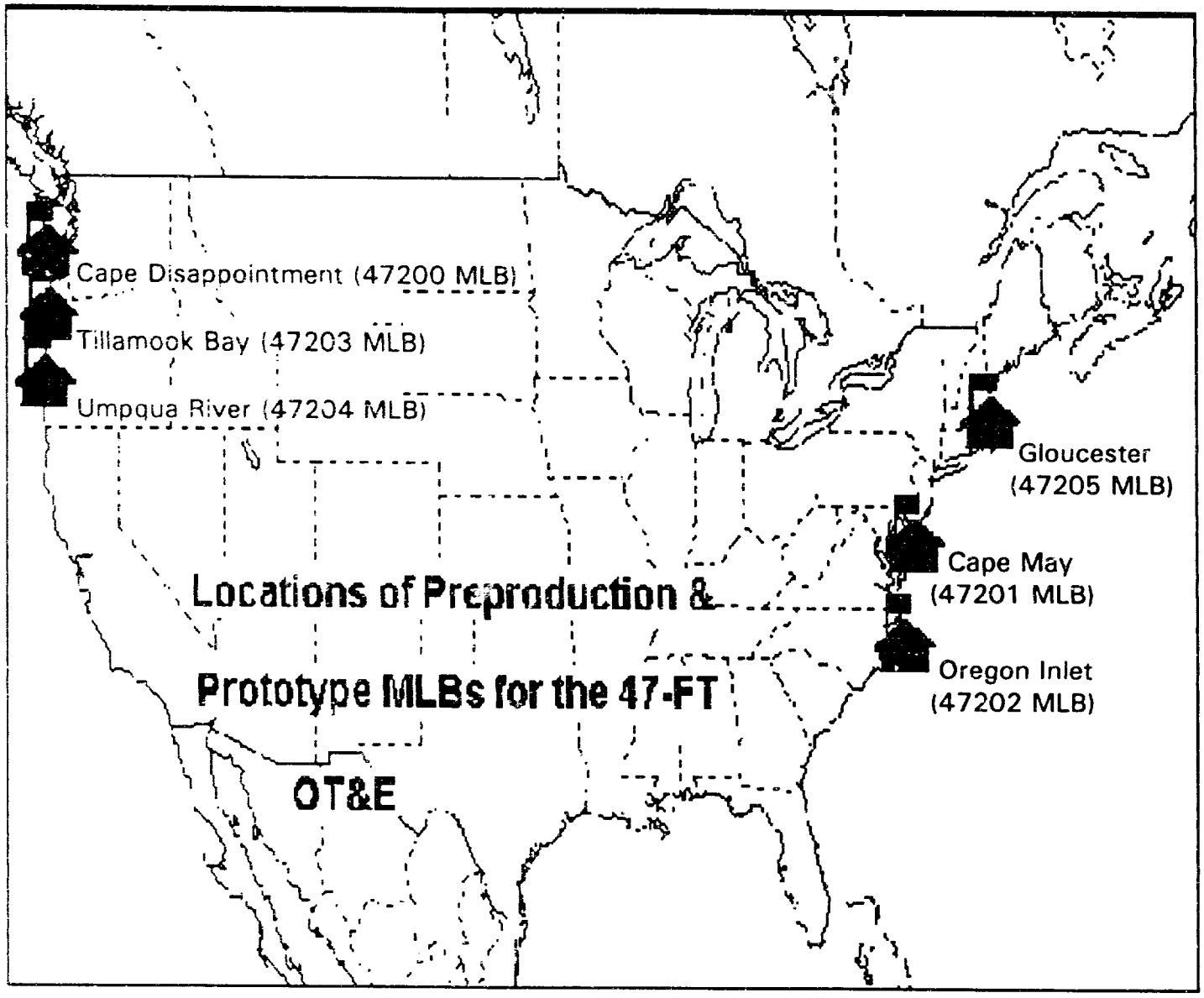


Figure 1. Geographic Locations of Preproduction and Prototype MLBs for the 47-FT OT&E

the unpredictable behavior exhibited in high speed turns and broaching in following seas during the DT&E. After a number of test iterations with different skeg/rudder configurations, a combination of smaller vertical rudders and no skeg were chosen as being optimal. The conversion from the 2.7 square foot canted rudders to 1.9 square foot vertical rudders is believed to have eliminated the excessive transient rolls during high-speed maneuvers and improved the handling characteristics with respect to the maneuvering problem identified. The long term investment involved in replacing the 44-FT MLBs with a capable replacement dictates the need for continued monitoring of the motion and maneuvering performance of the preproduction boats. This is necessary in case other problems or variations of the original problem are revealed during the OT&E. The MDR was developed to accomplish this monitoring function.

Two main objectives were established from the start of this project to collect motions data on the 47-FT MLB. They were as follows:

- The primary objective for the MDR is to have the ability to reconstruct a severe dynamic event such as a rollover when an established threshold is exceeded.

- The secondary objective for the MDR is to collect data to develop motion and underway time histories.

Cost was an additional constraint because MDR systems had to be developed for five MLBs.

A sixth MDR has recently been installed on the 47200 prototype, as well. Although the prototype is slightly different internally it has the same Deep Vee hull and diesel engines as the preproduction boats. Since the Motor Lifeboat Replacement Test Team located at the National Motor Lifeboat School completed their evaluations of the prototype, it has gone into operational use with Coast Guard Station, Cape Disappointment, WA.

The MDR was developed to function like an aircraft flight recorder "black box". The concept was to use a self-contained sensor package and data-logger to record the motions and control settings on the 47-FT MLB. The recorded data is played back after an incident to help reconstruct what actually happened. The minimum amount of information required to perform this function resulted in the selection of the following measurement parameters:

Motion Parameters

- heave acceleration
- pitch angle
- roll angle
- yaw angle (heading)

Boat Control Parameters

- rudder position
- port engine RPM
- starboard engine RPM
- port shaft direction (reverse or forward)
- starboard shaft direction (reverse or forward)

Boat's Position

- latitude and longitude

Figure 2 illustrates the desired information characteristics of the MDR. The minimum performance requirements which were established at the start of this project for the MDR were defined as follows:

- minimum autonomous operating time of 120 hours (30 days X 4 hours underway per day)
- storage of a minimum of 4 roll motion events
- status indicators to display MDR operating and memory status to crew
- 20 Hz sampling rate
- data readout in ASCII column format
- minimum 8 bit resolution

Various Development Efforts

MDR Computer: The datalogger selected for use as the heart of the MDR was a low power Tattletale Model 5. The Model 5 was outfitted with 2 Mbytes of expanded solid state memory to store the data collected on the 47-FT MLBs. The datalogger uses a streamlined version of the BASIC programming language called TTBASIC.

MDR Hardware: The MDR hardware, including circuit boards, housing, and interfaces were designed and fabricated by the R&D Center. The sensors used were selected off-the-shelf items.

MDR Mounting: Vibration isolation mounts were designed in-house to isolate the MDR from the propeller-induced structureborne vibrations. The mounts were tested at a vibration laboratory using a 1200 lb. shaker table. An MDR foundation plate was designed in-house to attach to each of the MLB's aft fuel cover plates using the existing bolt holes with longer bolts.

BOATVU: A computer animation capability was developed to play back computer generated images of virtual instruments and a solid wire-frame rendition of the 47-FT MLB's recorded motions. This program was adapted from an existing animation program to defray developmental costs.

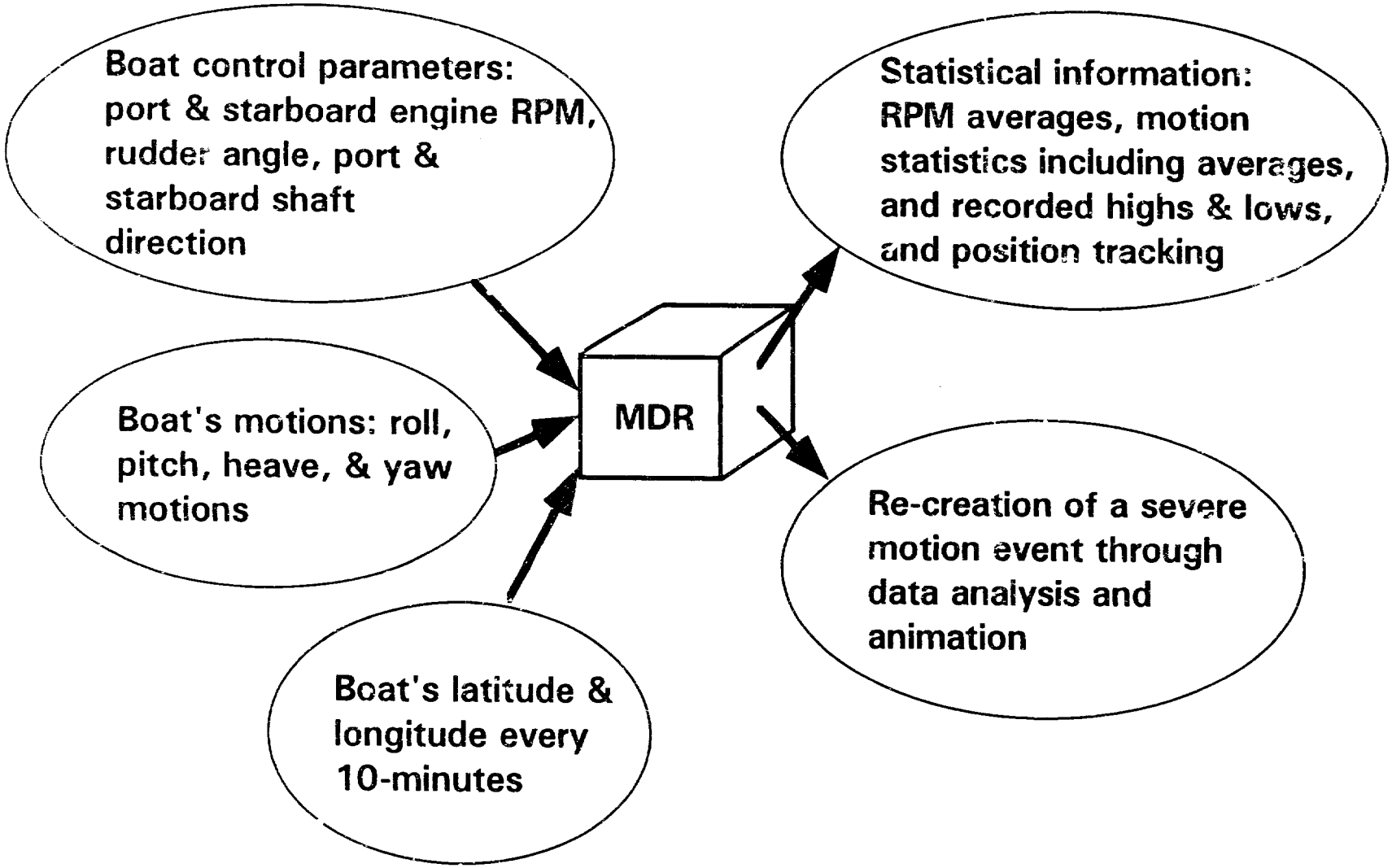


Figure 2. Information Requirements for a Mission Data Recorder

MDR Data Retrieval: A data retrieval scheme using a hand-held computer and communications software package was developed by the R&D Center to off-load data through an RJ-11 RS232 interface.

A listing of hardware and software used in carrying out this project is provided in Appendix G for information.

Prototype Testing at Station Cape Disappointment

A prototype MDR was developed and tested on the 47-FT MLB (47200) on 7 April 1993 at Station Cape Disappointment, WA. The original approach was to record the RPM and rudder position directly from the MLBs tachometers and rudder angle indicator. The attempt to read voltages directly from these sensors resulted in the MDR system loading down the boats sensors causing inaccurate readings. In order to completely divorce the MDR system from the 47-FT MLB's electronics, a rudder-position transducer and photo-optic tachs were used in the final configuration.

The MDR motion sensors were tested on 47200, together with the R&D Center's motion package used for seakeeping testing. The 47200 went through several maneuvers including turning circles and various wave encounters. During these maneuvers the MDR's threshold was artificially triggered to record several minutes worth of data. The peak-to-peak excursions measured by the MDR sensors and separate motions package were consistent.

DISCUSSION

MDR Functional Overview

The MDR was designed to operate autonomously with minimal crew participation. The MDR remains in a low power "stand-by-mode" and charges up its battery when the 47-FT MLB is on shore-tie. After a relay detects a shore-tie power disconnect, it turns on and begins data collection. The shore-tie is normally disconnected just before the boat gets underway. This enables the MDR to monitor the boat's motions from the moment it leaves the dock until it returns. After the shore-tie is reconnected the MDR resumes its low power "stand-by mode" and charges up its battery for the next mission.

The MDR houses the computer board, 2 Mbyte expanded memory board, battery charger, and 12V6Ah gell cell battery. The MDR has four internal sensors. Two electronic, pendulum-type sensors are used to measure roll and pitch angles of motion. A 4g accelerometer measures heave motions and a fluxgate compass is used to measure yaw angle. Figure 3 illustrates the major components inside the MDR.

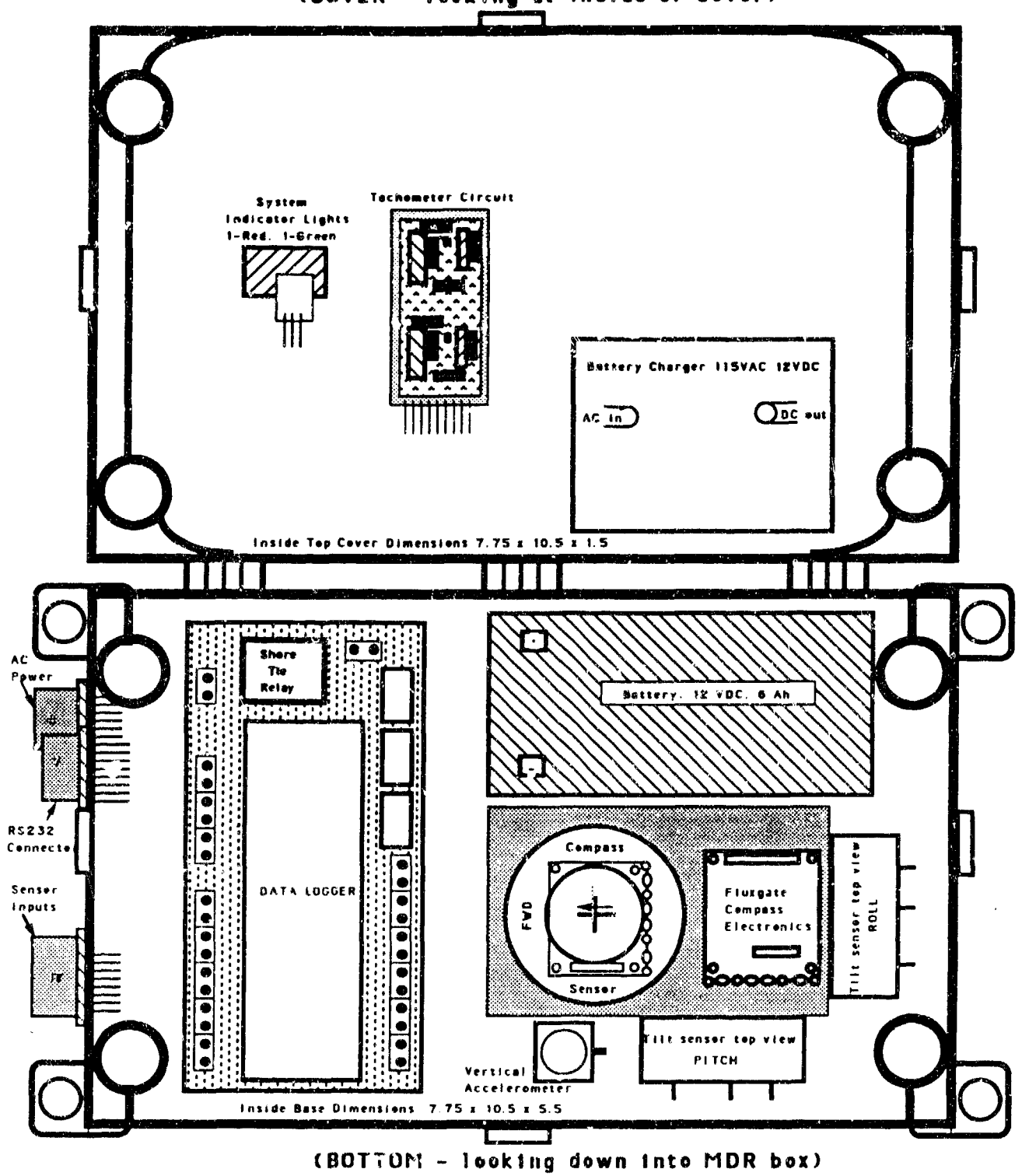


Figure 3. Major Components Inside the Mission Data Recorder

The MDR economizes storage space by recording data continuously in a revolving buffer at a 20 Hz sampling rate. When the MDR is on, the program collects 10 channels of information for a cycle of 10 minutes. During the 10-minute cycle, the MDR program continuously checks the roll sensor and determines if a threshold has been exceeded or not. If no event has been detected after the 10-minute cycle expires, the memory pointer goes to the beginning of the buffer and begins to collect new data. However, if an event is detected, the 10 minutes of information is saved as pre-event data. The program's progressive memory pointer moves to a different location and stores an additional two minutes of post-event data. Figure 4 illustrates this concept using bench test data where a roll threshold was set to 60 degrees. At sample number 2085, the roll sensor detects a value that exceeds the threshold. The memory pointer goes to 300 Kbytes (15,000 samples x 2 bytes x 10 channels) to initiate the 2 minute post-event cycle. A threshold software filter was added to eliminate the possibility of triggering on an artificial event such as a spurious voltage spike or extreme vertical acceleration.

The data in the 10 minute buffer is statistically reduced before the buffer is overwritten in the case of a non-event, saving the following:

- ♦ date and time
- ♦ heave RMS, heave average, highest heave value detected, lowest heave value detected
- ♦ pitch RMS, pitch average, highest pitch value detected, lowest pitch value detected
- ♦ roll RMS, roll average, highest roll value detected, lowest roll value detected
- ♦ average port shaft RPM
- ♦ ships position (lat/long)

If the shore-tie disconnect is not replaced and the internal 12V battery falls below 8.5 Volts, the system assumes a "sleep-mode" to retain recorded data. When this occurs, the MDR data can only be recovered by executing a hard reset. The internal MDR battery will collect three to five days of continuous data acquisition without recharging.

Figure 5 illustrates the program's operation. Further details including MDR schematics and program listings can be found in the 47-FT Motor Lifeboat Mission Data Recorder Development Manual [3]. The general performance characteristics of the MDR are listed in Table I.

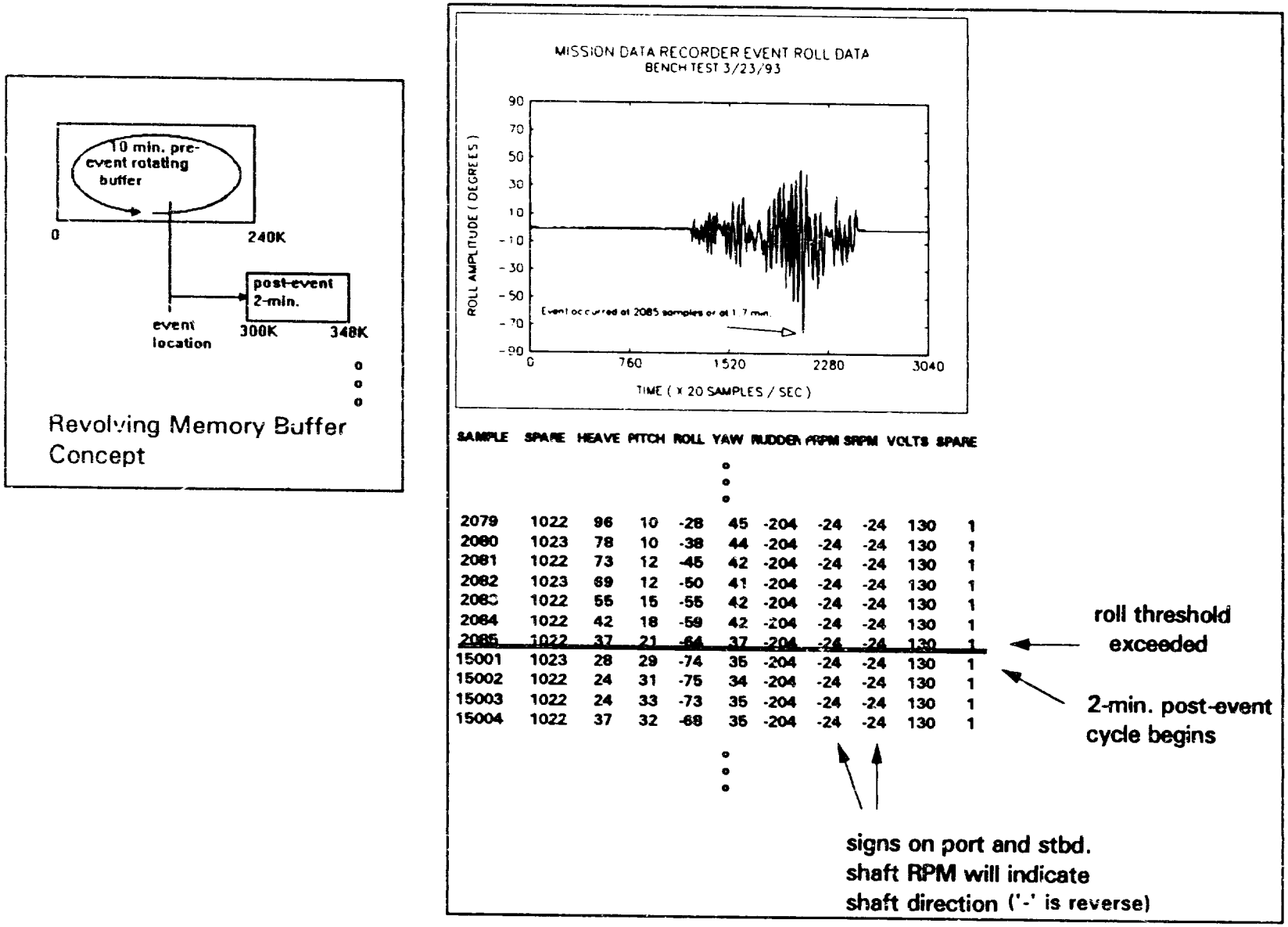


Figure 4. Mission Data Recorder Rotating Memory Buffer

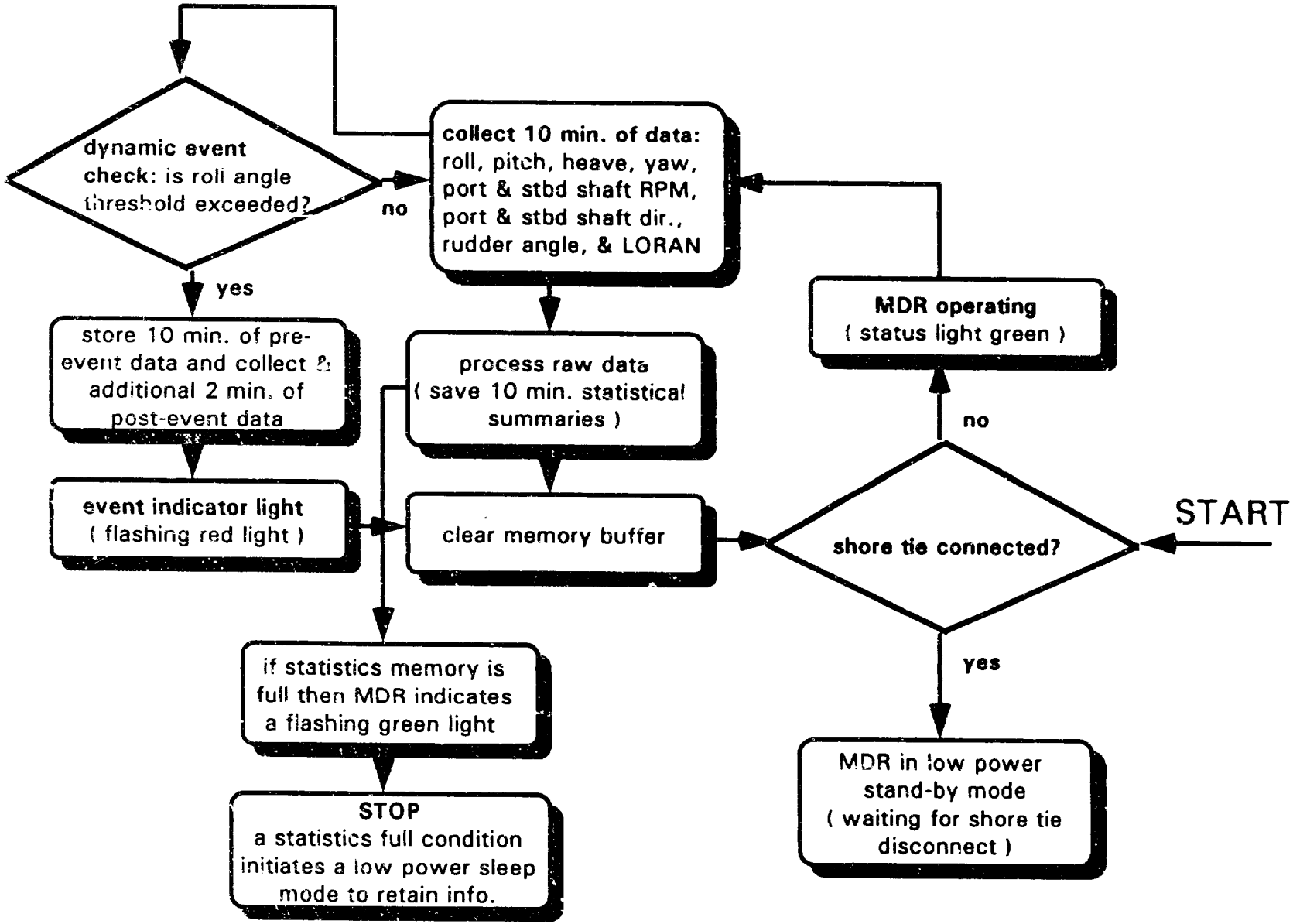


Figure 5. Functional Overview of the Mission Data Recorder

TABLE I
MISSION DATA RECORDER PERFORMANCE CHARACTERISTICS

Measurement Parameters

heave acceleration +/- 4g dynamic range
pitch angle +/- 175 deg range of motion
roll angle +/- 175 deg range of motion*
heading +/- 0.5 deg accuracy (gimbaled to +/- 45 deg)
port/stbd shaft RPM +/- 30 accuracy
rudder 0-150 deg range of motion
port/stbd shaft direction
LORAN lat/long**

Operational Parameters

autonomous operation of 110 days @ 4 hrs underway per day
storage of 5 events (12 minutes each)
20 Hz sampling rate
stores 10 minute statistical summaries
status lights indicate memory condition

Cost

less than $8000.00 per unit (hardware costs only, as constructed by the R&D Center)

* MDR lab tests demonstrate box can accurately track a 360 degree roll. MDR software can be configured to trigger off any sensor or combination of sensors to capture a specific motion phenomenon.

** Program can be adapted to decode GPS signals.

MDR Installations

Installation Schedule

The MDRs were installed on the five preproduction boats when they became available. The boats were put in "Charlie" status for three days to install the MDR hardware and software, calibrate the sensors, and perform checkout tests with the boat underway. The initial MDR installation and checkouts were performed as follows:

MLB	INSTALLATION SCHEDULE	MDR NO.	ROLL THRESHOLD
47201	27-30 SEP 1993	MDR No.1	30 degrees
47202	25-29 OCT 1993	MDR No.2	45 degrees
47203	16-18 NOV 1993	MDR No.3	45 degrees
47204	21-24 JAN 1994	MDR No.4	45 degrees
47205	31 JAN - 3 FEB 1994	MDR No.5	45 degrees
.....	.....	.....	.....
47200	14-16 MAY 1994	MDR No.6	60 degrees

A set of second visits were required to upgrade rudder sensors that were having mechanical problems with the rudder sensor string pots and to generally check the system integrity. These visits were performed as follows:

MLB	VISIT SCHEDULE
47201	3/11/94
47202	2/27/94
47203	3/24/94
47204	2/25/94
47205	trip not required
.....	.....
47200	trip not required

MDR Hardware Installation

The MDR box was installed on the aft fuel cover plate in the survivor's compartment approximately 14½ feet forward of the aft perpendicular and three feet above baseline. This installation site is located near the center of gravity of the 47-FT MLB. A one-half inch thick aluminum foundation plate interfaces with the existing bolt hole pattern on the cover plate. Four mounts were used to isolate high frequency vibrations including propeller-induced structureborne vibrations. This was necessary because of the importance placed on the MDR measuring rigid body motions of the 47-FT MLB and not unrelated boat vibrations. Figure 6 presents a photograph of this installation.

Two banner photoelectric polarized retro-reflective sensors were installed on the port and starboard cardan shafts to record engine RPM. The cardan shaft is located between the engine and

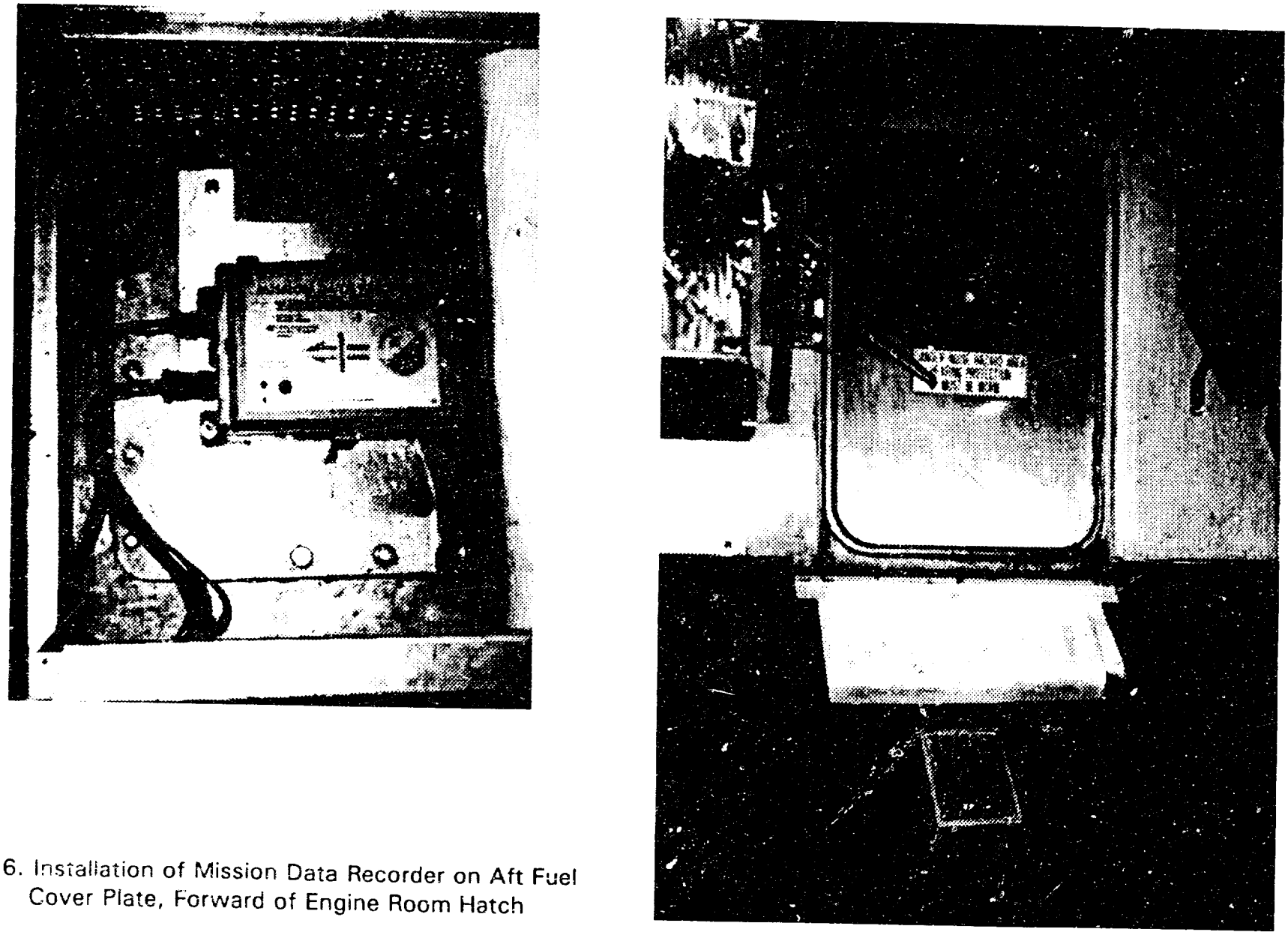


Figure 6. Installation of Mission Data Recorder on Aft Fuel Cover Plate, Forward of Engine Room Hatch

reduction gear of the 47-FT MLB's vee drive system. The sensors are mounted on the outboard framing near frame 6. Reflective tape was adhered to the cardan shaft in-line with each sensor. These RPM sensors draw power from the boat's 12V DC panel and draw a maximum of 25 milliamps. Figure 7 presents a photograph of a photoelectric tach as installed on the 47-FT MLB.

Two micro-switches were installed in each reversing gear box to measure throttle or shaft direction. The switches are engaged by the cam at the end of the linkage inside the box. A signal is sent to a digital I/O port on the MDR and is assigned a negative value if the shafts are in reverse. Figure 8 presents a photograph of a micro-switch installed on a 47-FT MLB.

A ruggedized string potentiometer was installed in the Lazarette to measure the rudder position. The rudder angle sensor is a sealed string pot which has a stainless steel leader attached to the rudder post. Figure 9 presents a photograph of the rudder sensor attached in the Lazarette.

The MDR measures the boat's position through a 'Tee' connector installed in the back of the LORAN set which is located in the enclosed bridge. The 47-FT MLB has two LORAN units. One is located in the enclosed bridge and one is up on the flying bridge. The MDR program extracts latitude and longitude information every 10 minutes from the NMEA 0183 interface on the LORAN-C sets. The position sampling rate is not frequent enough for detailed track reconstruction. However, this information is used for plotting Areas of Recorded Operations (AROs) using the newly developed Geographical Display Operations Center (GDOC) software which is undergoing testing.

Several bulkhead penetrations had to be made to accommodate the MDR system. In the first installation on the 47201 at Station Cape May, water-tight stuffing tubes were used. In the remaining installations the existing Multiplug penetrations were utilized to eliminate the need to drill any holes through the bulkheads. Figure 10 illustrates the bulkhead penetrations required and general wiring layout. Figure 11 illustrates a system wiring diagram.

The installations took three days, required three R&D Center personnel, and required that the boat be in "Charlie" status. The wiring and hardware installation normally took two days. The third day was required to calibrate the sensors and "store" the values into the MDR's Read Only Memory (ROM). The MDR was artificially triggered for each boat, dockside, to collect baseline data on the motion sensors. Typically the roll and pitch readings deviated from zero (level plane) no more than 1 to 2 degrees at the most. A system check was performed by setting a temporary threshold value to 10 degrees and then taking the boat out for maneuvers to trigger the recording of roll events. These data were analyzed to determine if all channels were working properly.

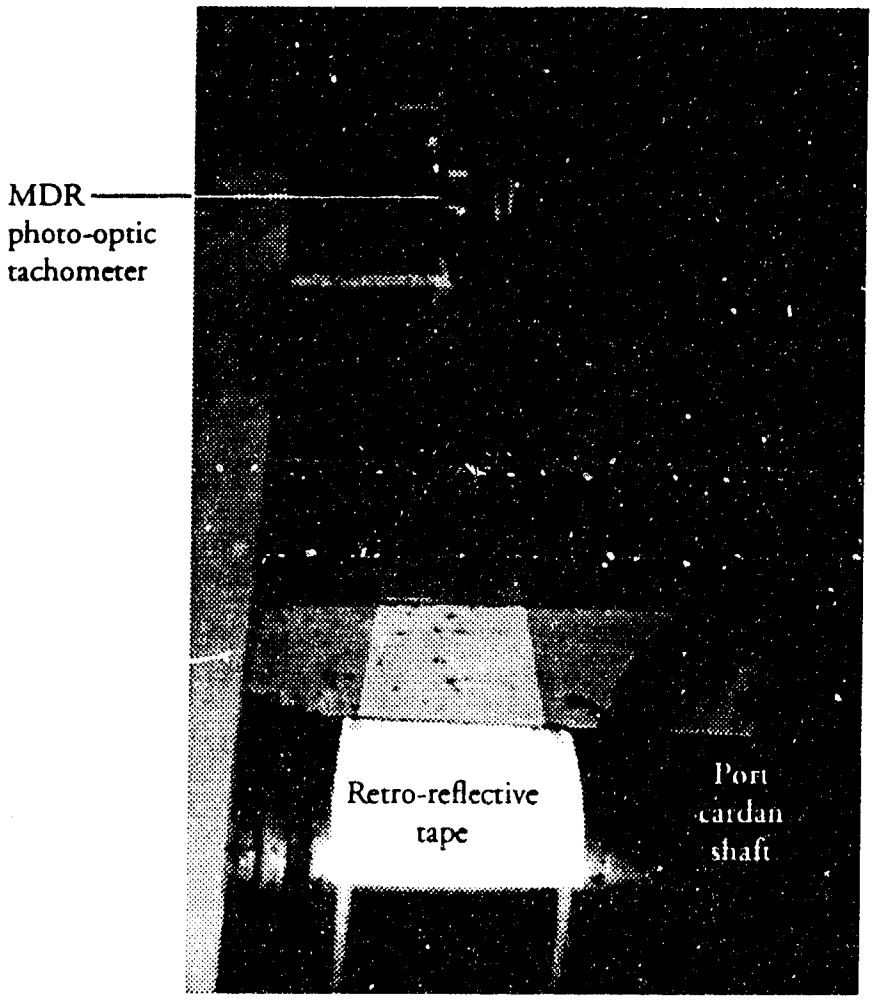


Figure 7. Starboard Photo-Optical RPM Sensor as Installed on the 47-FT MLB

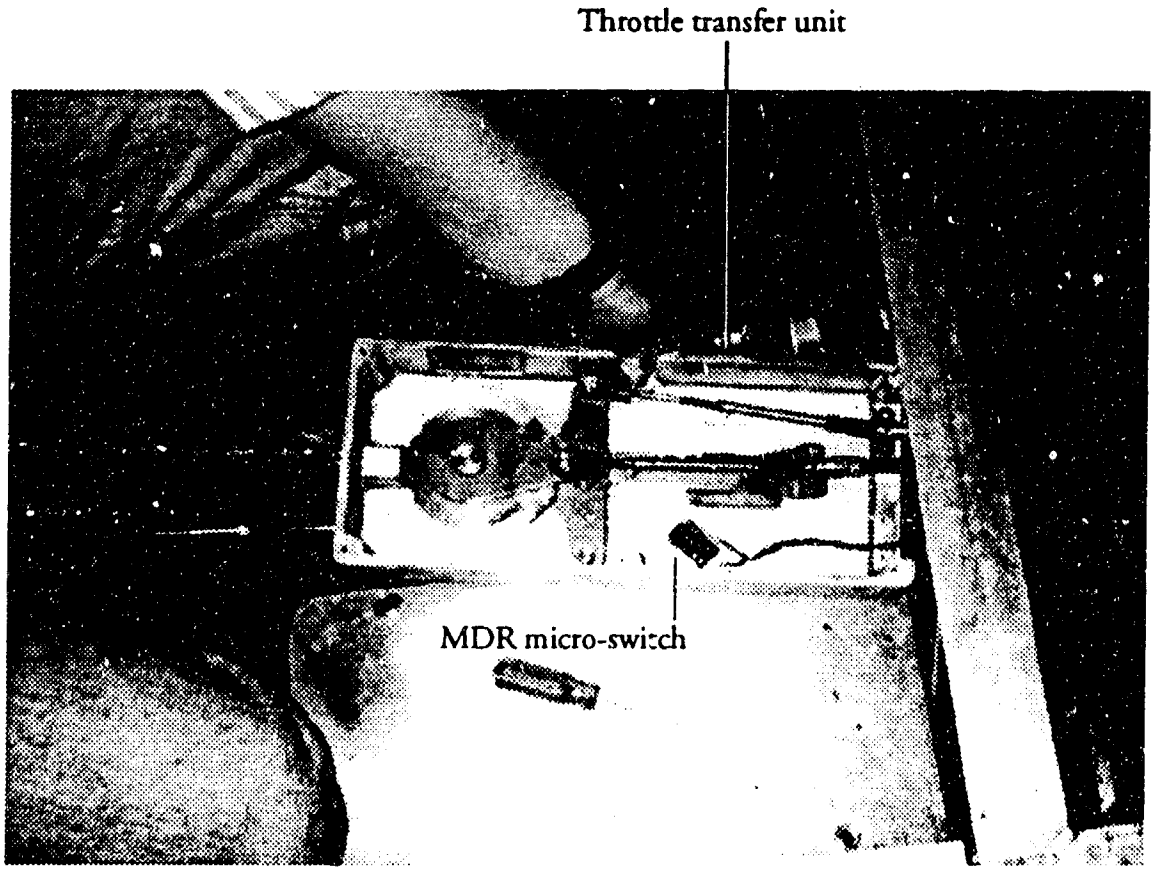
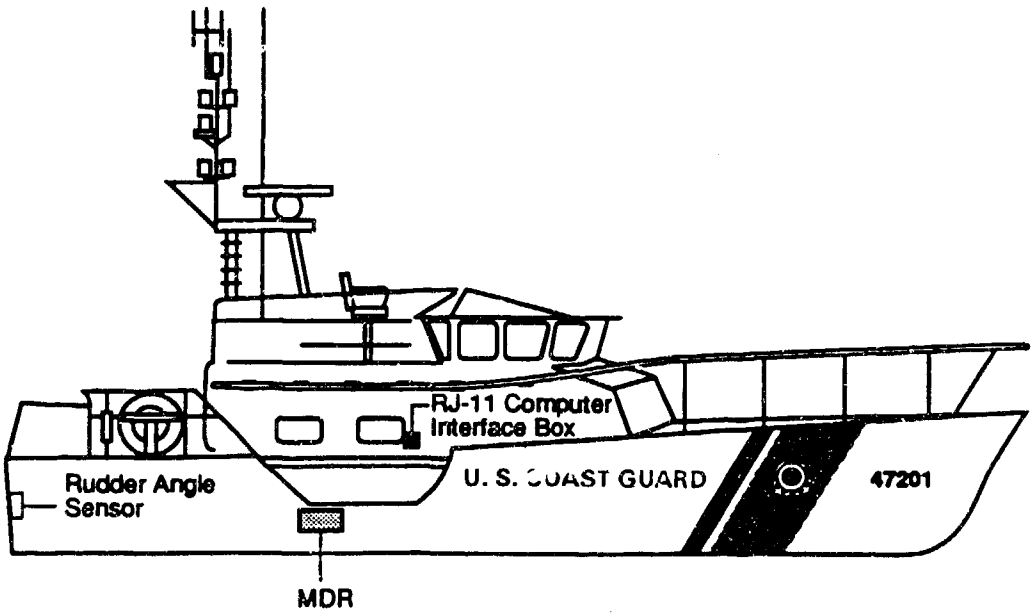


Figure 8. Micro-Switch Measures Shaft Direction on the 47-FT MLB

Figure 9. String Potentiometer Installed in the Lazarette of the 47-FT MLB



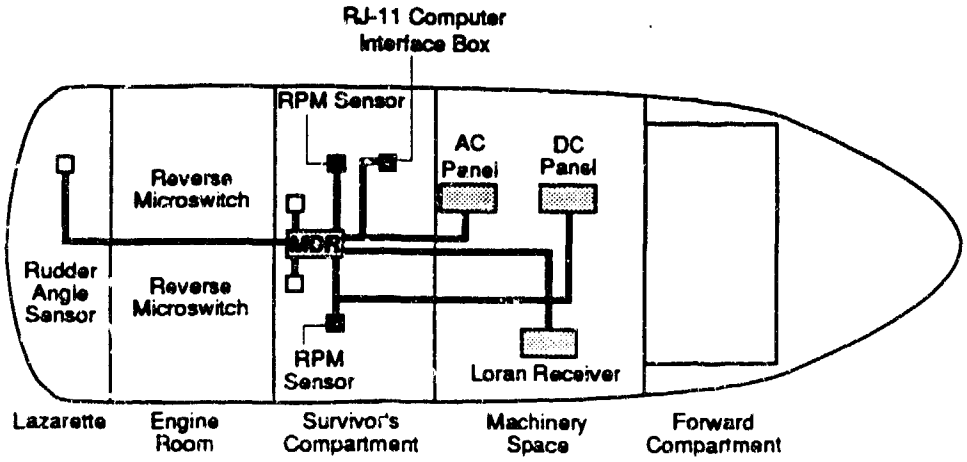


Figure 10. Mission Data Recorder Wiring Layout and Bulkhead Penetrations

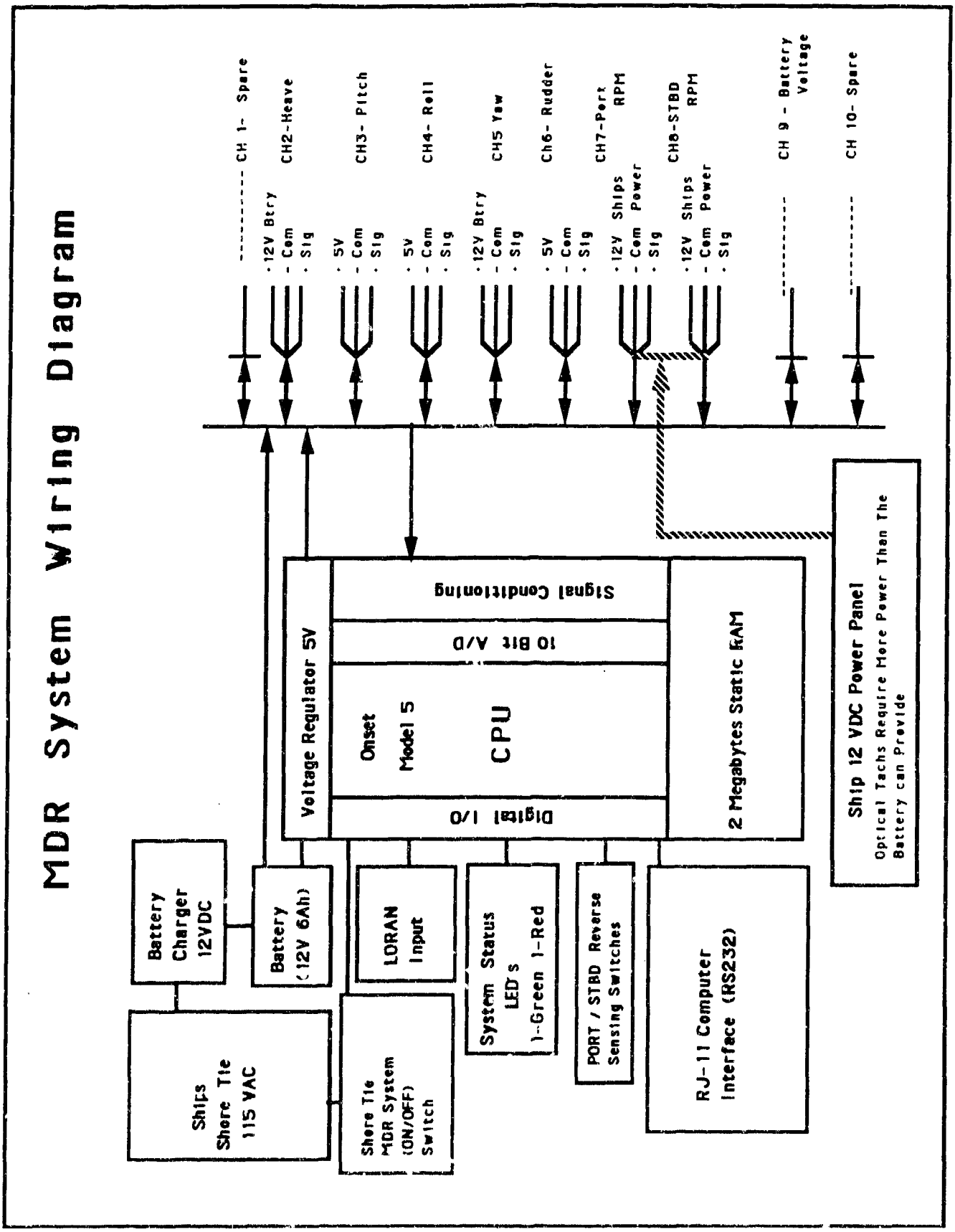


Figure 11. MDR System Wiring Diagram

MDR Post Processing

Events Recorded

Table II summarizes the motion events that have been recorded as of 12 June 1994. A sample of a full report is contained in reference [5], available on request.

TABLE II
MOTION EVENTS RECORDED BY THE MISSION DATA RECORDER

Station	Event Time/Date
Station Cape May	13:35 on 12/15/93 13:33 on 2/18/94 10:38 on 3/3/94 13:43 on 5/12/94
Station Tillamook	17:31 on 6/12/94
Station Oregon Inlet	13:44 on 12/1/93 13:59 on 12/1/93 14:12 on 12/1/93 13:26 on 12/2/93
Station Umpqua River	no events detected
Station Gloucester	no events detected

Appendices A through F contain the results of the data analysis for the 47201, 47202, 47203, 47204, 47205, and 47200, respectively. Each Appendix contains a summary table for each event recorded, the resulting time histories, snapshots of animations if performed, accumulated statistical results to date, and ARO plots.

Each event recorded and analyzed has a summary plot which presents the 12-minute time histories of the 7 MDR sensors. This is illustrated in Figure 12. A closer inspection is made around the event in a 25-second time history expanded plot which depicts the 5 seconds before and 20 seconds after the event.

Data Offloading

A number of options were considered for offloading data from the MDR. A direct modem link to the MDR was considered not practicable because of the slow transmission rate (9600 baud) of the datalogger and because of the logistics involved in getting phone lines on-board the 47-FT MLBs at each station.

Unfortunately, there was no cellular phone coverage at the more remote stations. Even if a cordless system were available to all

Event Summary Plot Key:

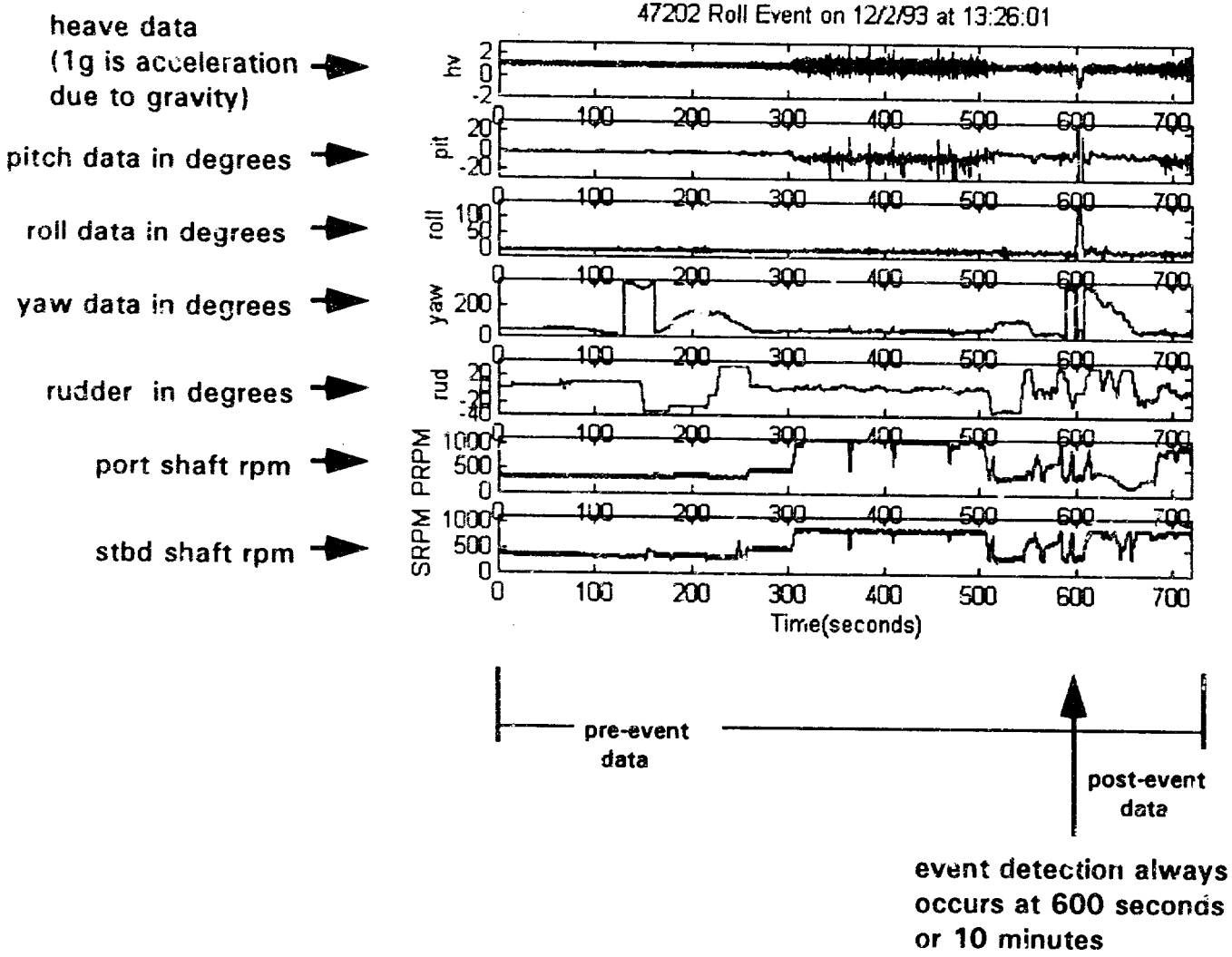


Figure 12. Event Summary Plot Key

of the stations, the costs associated with transmitting this much data would have been high. The method chosen to off-load MDR data was to send a hand-held computer with a batch routine on a rotating basis to each station. This is performed periodically to off-load the data or reset sensor thresholds.

Unless a significant motion event is recorded, the R&D Center routinely mails a hand-held computer to off-load the MDR data and to reset the internal clock. The crew is asked to connect the hand-held computer to the phone jack located in the survivor's compartment. The general setup is demonstrated in Figure 13. The crew member initiates the batch program which automatically off-loads the 2 MByte file, resets the roll sensor threshold, and clears the memory. The data is stored in a 4 Mbyte RAM memory PCMCIA card. The crew member must enter the time and date to the prompts on the screen. It takes about one hour to perform this task. The hand-held computer is then mailed back to the R&D Center.

Area of Recorded Operations (AROs)

The Area of Recorded Operations (AROs) is defined as the latitude and longitude locations recorded by the MDR for the purposes of this report. This is not to be confused with Areas of Responsibility (AORs). The MDR records position fixes every 10 minutes when the MLBs are underway. The navigational information is decoded from the LORAN set in the enclosed bridge.

A program was written to convert the MDR ASCII output to a format compatible with the Geographical Display Operations Computer (GDOC). This program was developed by the Coast Guard Electronic Engineering Center. The MDR position data are displayed as scatter plots over vector charts about each of the six stations. The level of detail can be improved by zooming in. Raster charts can also be utilized and read from a CD-ROM drive. The level of detail provided with the vector charts was considered adequate for this study. The user can click on any of the data points to display a window containing the date and time for that recorded location. Figure 14 provides a key to the interpretation of the MDR ARO plots.

Animation Routine

A post-processing routine was developed to animate the data collected with the MDR. The program is called BOATVU. User documentation can be found in the BOATVU User's Manual [4]. The program plays back event data through instrument gauges and dials on the computer screen. These virtual instruments represent the boat parameters recorded with the MDR. A wireframe 3D rendition of the 47-FT MLB can simultaneously be displayed with the operating instrument gauges. Figure 15 illustrates the MDR data

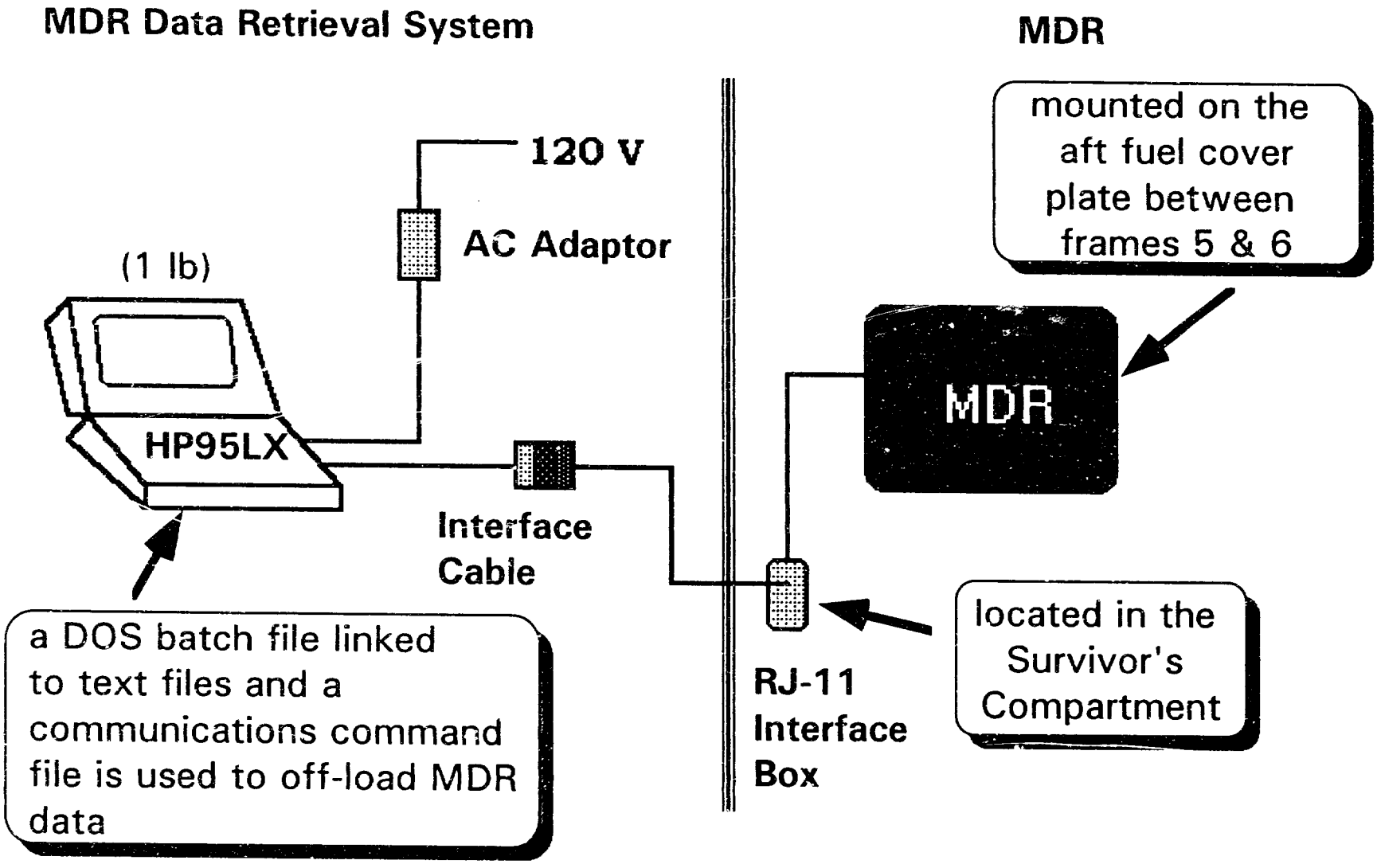


Figure 13. Mission Data Recorder Data Retrieval System

Area of Recorded Operations (AROs) using the Geographical Display Operations Computer (GDOC) Summary Plot Key:

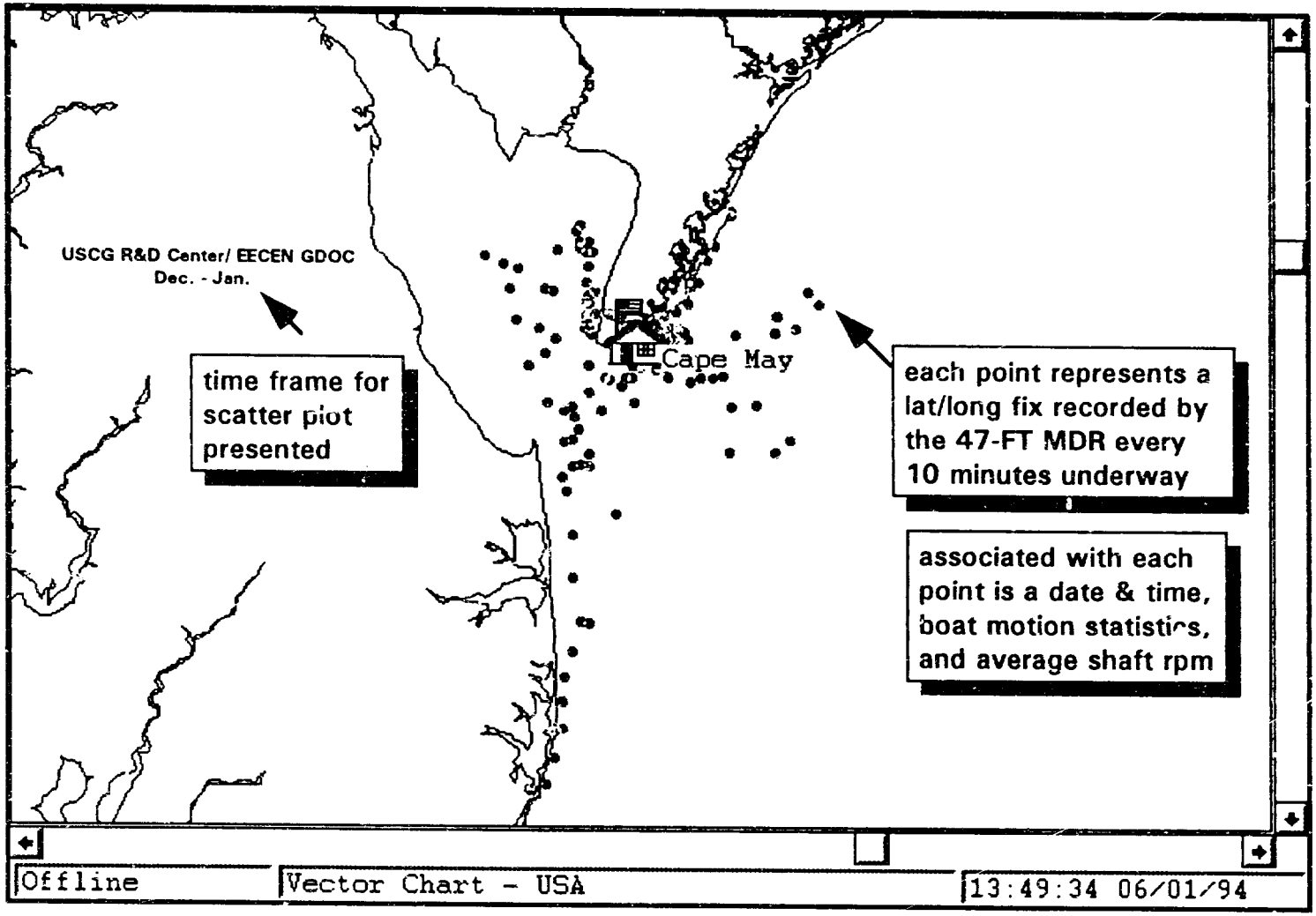


Figure 14. Area of Recorded Operation (ARO) Plot Key

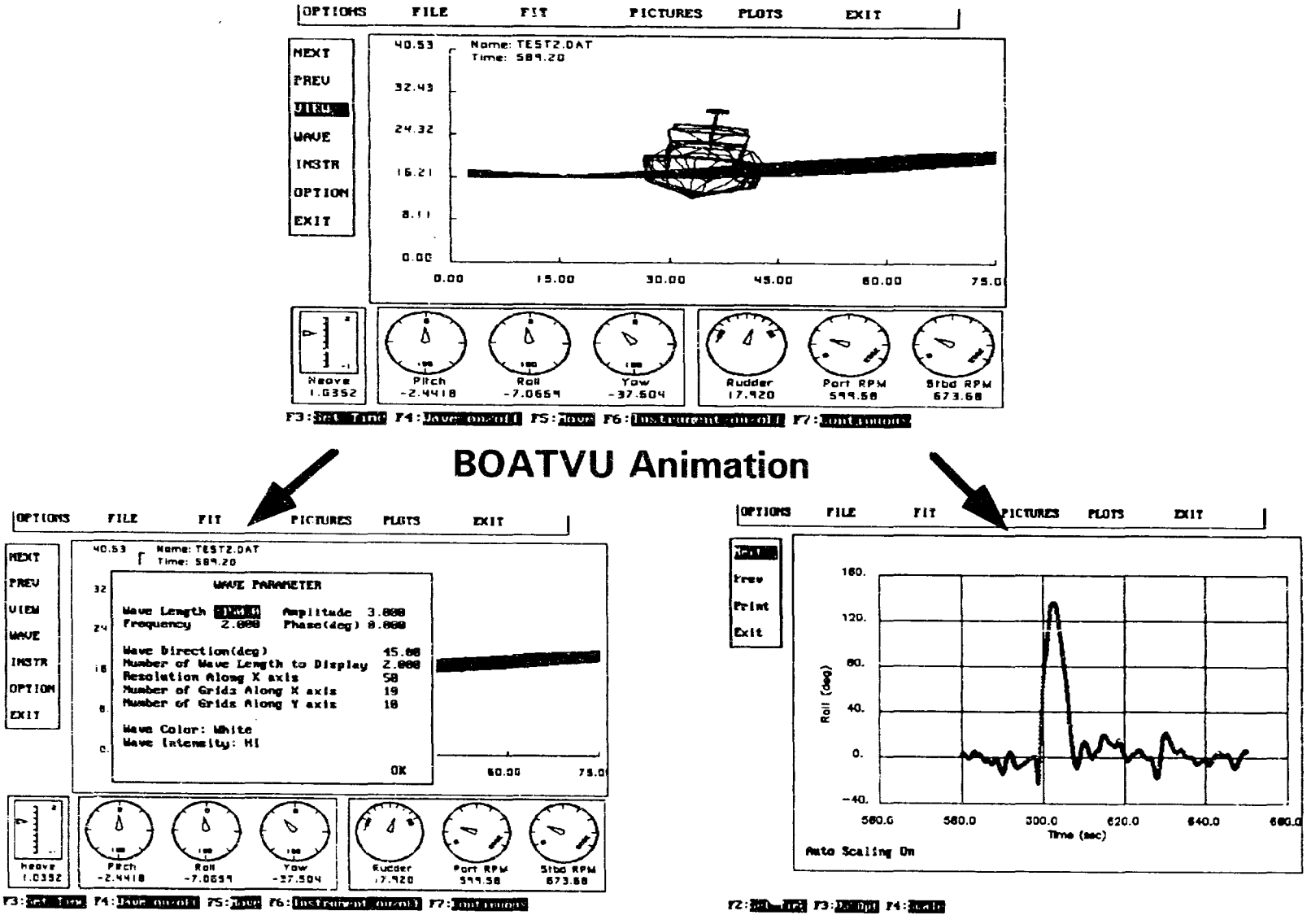


Figure 15. Display of the BOATVU Animation Program Picture Screen

animation capabilities. The MLB animation is based on the MDR motion data of roll, pitch, yaw, and heave. Figure 16 provides a key to interpreting the virtual instrument displays. The accelerometer data is integrated twice to estimate the vertical displacement.

Wave information is not collected with the MDR. Qualitative information on wave characteristics can be derived from either National Data Buoy Center (NDBC) spectra or from eyewitness accounts from the MLB coxswain or crew. Although wave characteristics are not actually measured, a user defined sinusoidal wave can be synchronized to the MLB animation. A single moving sinusoidal waveform can be defined by its amplitude, wavelength, frequency, and phase and its direction in the X-Y plane. The MLB wireframe model can be translated to any initial starting location with respect to the wave.

Heave displacement was calculated through a double integration of the accelerometer time history data. The accelerometer data along with roll and pitch are low-pass filtered around 1 Hz. A 1 Hz second order Butterworth Filter is used to eliminate unwanted noise while retaining sufficient rigid-body motion information for the animation routine. The heave acceleration is transformed from the boat coordinate system to the inertial system and a constant 1g factor is removed to account for constant acceleration due to gravity. A moving average technique was used to minimize bias problems encountered in the acceleration data. In general, the animation package must be used with discretion and is only good for providing a gross approximation to the recorded motions.

CONCLUSIONS

Discussion of Events Recorded During the OT&E

47201 at Station Cape May:

The MDR captured several 30-degree roll events from 47201 that were not very remarkable. These were collected on 15 December 1993, 18 February 1994, and 12 May 1994. These data are presented in Appendix A for consistency. However, the 47201 did experience a 53-degree roll on 3 March 1994 which was more interesting. The data collected on this event are presented in Table A-3 and Figures A-10 through A-18. Although this was only a 53-degree roll, the MLB spent nearly four seconds past 45 degrees. This was a pitch event as much as a roll event. Just as the 47201 began the 53-degree roll sequence, it rapidly pitched down to a maximum of 35 degrees. This is illustrated in Figures A-13 and A-18. As evident in Figure A-13, 47201 hovered around 50 degrees of roll to starboard for about three seconds. Snapshots of the animated roll event sequence are shown in Figures A-19 through A-23. The 47201's starboard engine stalled

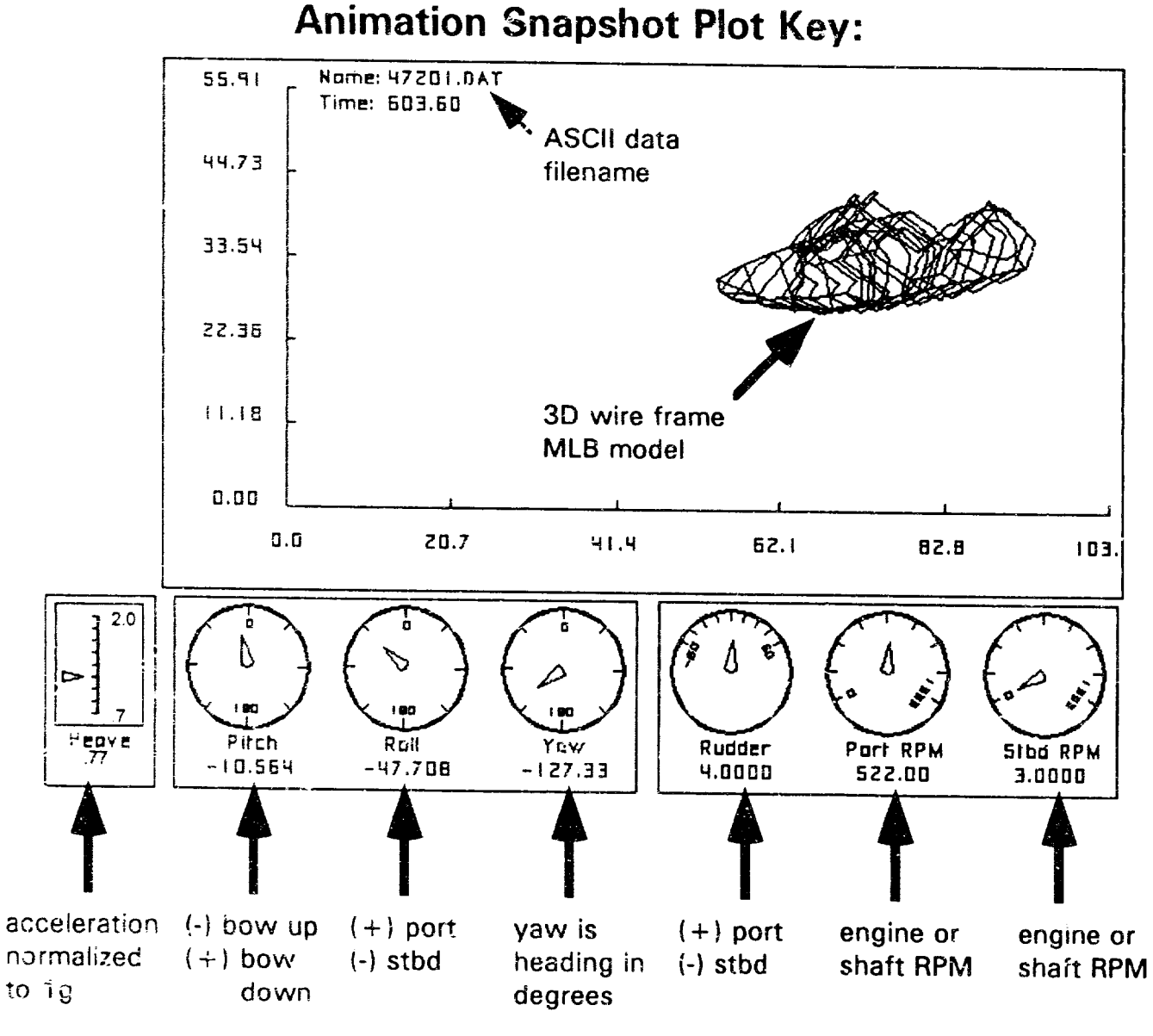


Figure 16. Key to Interpretation of Virtual Instruments

immediately after a roll event was detected. It took nearly one minute to restart the engine and to match the port RPM tachometer. This is illustrated in Figure A-16.

47202 at Station Oregon Inlet:

At Station Oregon Inlet, 47202's MDR recorded three events on 1 December 1993. They were at 1344, 1359, and 1412, all within a half-hour of one another. The first event was not a true event as defined by the 45-degree roll threshold established for the 47202 MLB. The data collected for this event are presented in Table B-1 and Figures B-2 through B-5. The recording of this event was triggered by several consecutive high roll sensor values which exceeded the threshold setting. However, these values are the result of the roll sensor's damping limitations. Although a software filter in the MDR program is used to minimize the recording of non-events, the MDR will occasionally record them. The trade-off to record the occasional non-event overshadowed the alternative of desensitizing the roll detection scheme too much. The actual maximum roll in this case was approximately 28 degrees to starboard. This is illustrated in the roll time history plot in Figure B-5.

The data recorded for the second event on 1 December at 1359 are presented in Table B-2 and in Figures B-6 through B-14. The 47202 experienced a 47-degree roll to port as shown in Figure B-9. Both port and starboard engine RPM were near cruising speed before, during, and a few seconds after the event. Just prior to the recorded event, the rudder was rapidly moved from 25 degrees starboard to 13 degrees port, then hard to starboard. This is shown in Figure B-14. From Figure B-9, it is evident that the MLB experienced a series of 10 to 30-degree rolls immediately after the 47-degree roll.

Once again in the third event recorded the same day at 1412, a set of consecutive motions from different directions caused the recording of a non-event. These data are presented in Table B-3 and in Figures B-15 through B-18. The approximate maximum roll recorded was 30 degrees to starboard as illustrated in Figure B-18.

There have been only a few noteworthy roll motion events in the course of this phase of the 47-FT OT&E. The most severe roll event was recorded on 47202. The 47202 rolled to 137 degrees and spent 5.25 seconds past 90 degrees. These data are presented in Table B-4 and in Figures B-19 through B-25. According to the "Class C Marine-Related Mishap Report" from Station Oregon Inlet, the 47202 was deliberately placed by the coxswain, starboard side beam to a set of well-developed waves. The 47202 decreased to clutch speed just before the roll event and experienced a quick 30-degree roll to starboard followed by a slow port roll to 137 degrees. Snapshots of the animated roll event sequence are shown in Figures B-26 through B-29. Some of the time history plots

from this event are included in this report for completeness but more detail can be found in the original event report in Reference [5]. In this particular case, because the vessel was at clutch speed and making only a couple of knots headway just before the event, it was essentially a static test of the boat's righting capability to a ten-foot plunging, breaking wave (as reported by the coxswain). The MLB performed as designed and the large righting arm at 140 degrees prevented the MLB from rolling completely over.

Both engines increased RPM immediately after this event. However, the port engine quickly lost RPM and fell below clutch speed. This is illustrated in Figure B-25. It took nearly one minute to restart the engine and match it to the starboard engine. This is the second case where one of the two engines failed after a significant roll event and where it would take nearly a minute to recover. The recording of this event on the 47202 has provided the first opportunity to capture the data from a roll of this magnitude in actual operating conditions.

47203 at Station Tillamook:

One motion event was recorded on 47203 on 12 June 1994. These data are presented in Table C-1 and in Figures C-2 through C-15. The 47203 experienced several 10-degree rolls in the minute preceding the event detection. The MLB experienced a 10-degree roll to port before slowly rolling to starboard to a maximum of 72 degrees as illustrated in Figure C-5. After the MLB reached this maximum roll value, it rapidly righted itself to an even keel in less than 2.3 seconds. A snapshot of the roll animation sequence is presented in Figures C-16 through C-20. For approximately two minutes before the event was detected, both engines were running at near cruising speed. Both engines were reduced rapidly to clutch speed approximately 10 seconds before the event sequence began. During the roll sequence, the engine RPM was quickly increased to 1800 and 1600 port and starboard RPM, respectively, and returned to near clutch speed for about two minutes. In this severe motion event, the engines remain on-line immediately after the roll event. The only difference unique to this event was that the engines were throttled up during the roll-over sequence. This is illustrated in Figures C-14 and C-15.

Motion Statistics

The motion statistics for each boat are summarized for the average roll, pitch, heave, and RPM data into monthly values. These are presented in the Appendices of the respective MLB (Appendices A-F). The data have also been processed on a average daily basis which may provide a better "flavor" for the different levels of motions recorded by the boats at different geographical locations. These data are available upon request. Heave RMS while underway averaged around 0.1 g. The average of the highest

recorded heave values for the majority of the boats was around 0.15 g's except for the 47201 located at Station Cape May, NJ, which recorded lower values around 0.11 g's. The highest pitch averages were recorded on the 47203 at Station Tillamook, OR. The highest roll RMS averages were also found in the data recorded on the 47203.

Area of Recorded Operations

The AROs are presented in the Appendices of the respective MLB. A perimeter was drawn around the recorded position data to indicate the bounds to each boat's underway locations.

Recommended Phase 2 OT&E Evaluations of the 47-FT Preproduction MLBs

It needs to be emphasized that the MDR as presently developed only records the response of the MLB to environmental forces. The evaluations made of the events recorded so far are one-sided. The input to the event picture can only be established from subjective eyewitness accounts from the crew and possible wave spectra data from distant NDBC wave buoys. In Phase 2 of the OT&E, the R&D Center will continue to collect motion events with the MDR and will interview the coxswains by presenting the animations and data on events recorded to elicit feedback to develop an improved picture of what happened. The interviews will also uncover whether or not the R&D Center should re-evaluate the MDR's definition of what an event is in order to capture other more important boat maneuvering concerns that the coxswains have experienced in the course of this phase of the OT&E.

REFERENCES

[1] Operational Test and Evaluation Plan for the 47' Motor Lifeboat

[2] Technical Characteristics Verification of the Prototype 47-FT MLB, Coast Guard R&DC Final Report No. CG-D-02-92, October 1991

[3] 47' Motor Lifeboat Mission Data Recorder Development Manual - Version 2, R&D Center Unpublished Document, Available upon Request

[4] BOATVU User's Manual, by GESAC, Inc. for the US Coast Guard R&D Center, Available upon Request

[5] Enclosure (1), "47 FT MLB/MDR Event Report, 47202, 12/2/93" to RDC ltr 3900/749209 to G-NRS dtd 21DEC93

APPENDIX A

47201 DATA RESULTS

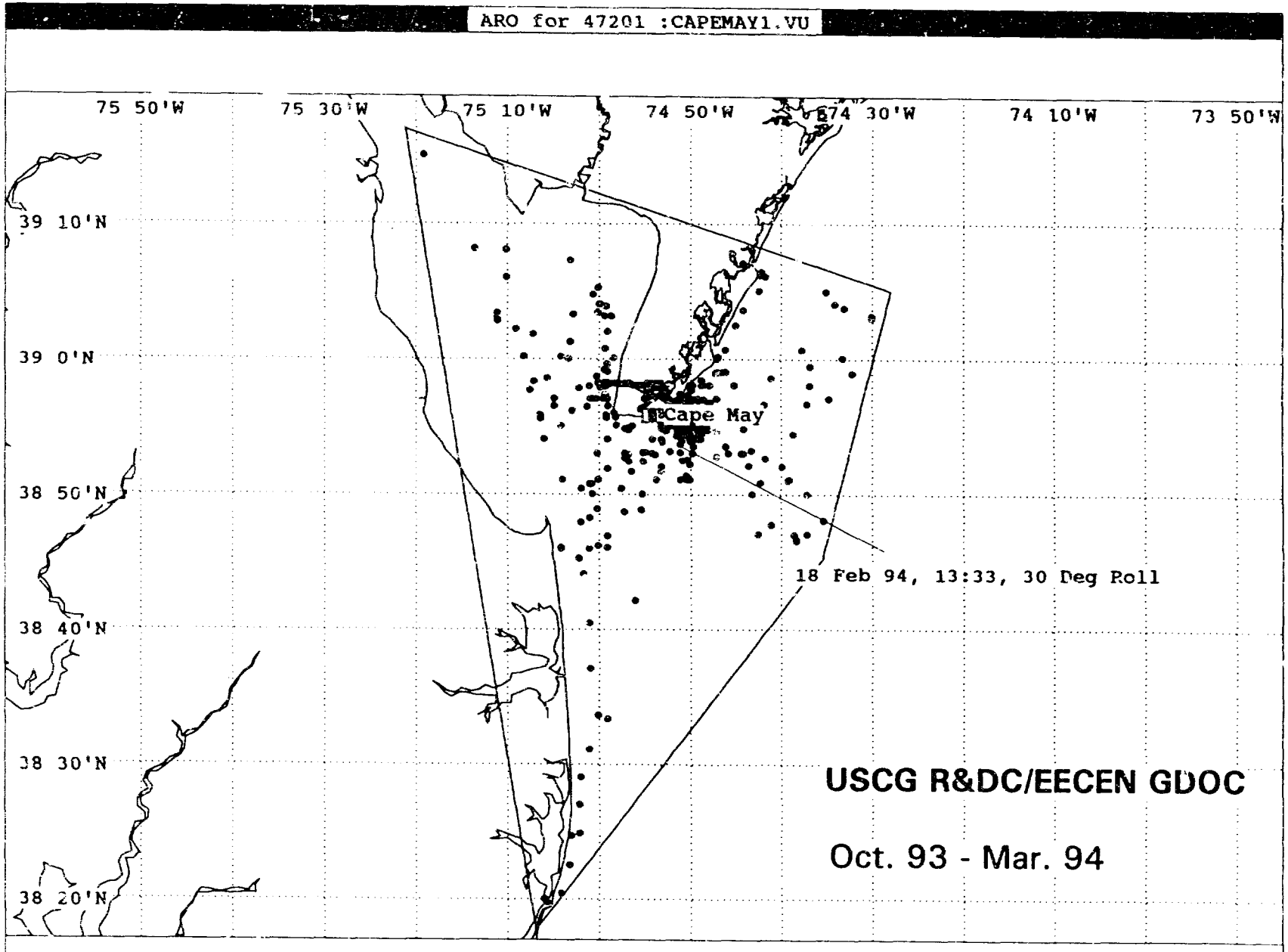


Figure A-1. Area of Recorded Operations for 47201

TABLE A-I. 47201 EVENT SUMMARY TABLE

Summary of Data Collected with the MDR

Boat: 47201
Date: 15 DEC 93
Dock Departure (Shore-tie Disconnected):
Time of Event: 13:35:06
Location: Not Recorded
Maximum Roll Angle Detected: 31 degrees
Time Spent Past 90 Degrees: N.A.
Time Spent Past 45 Degrees: N.A.

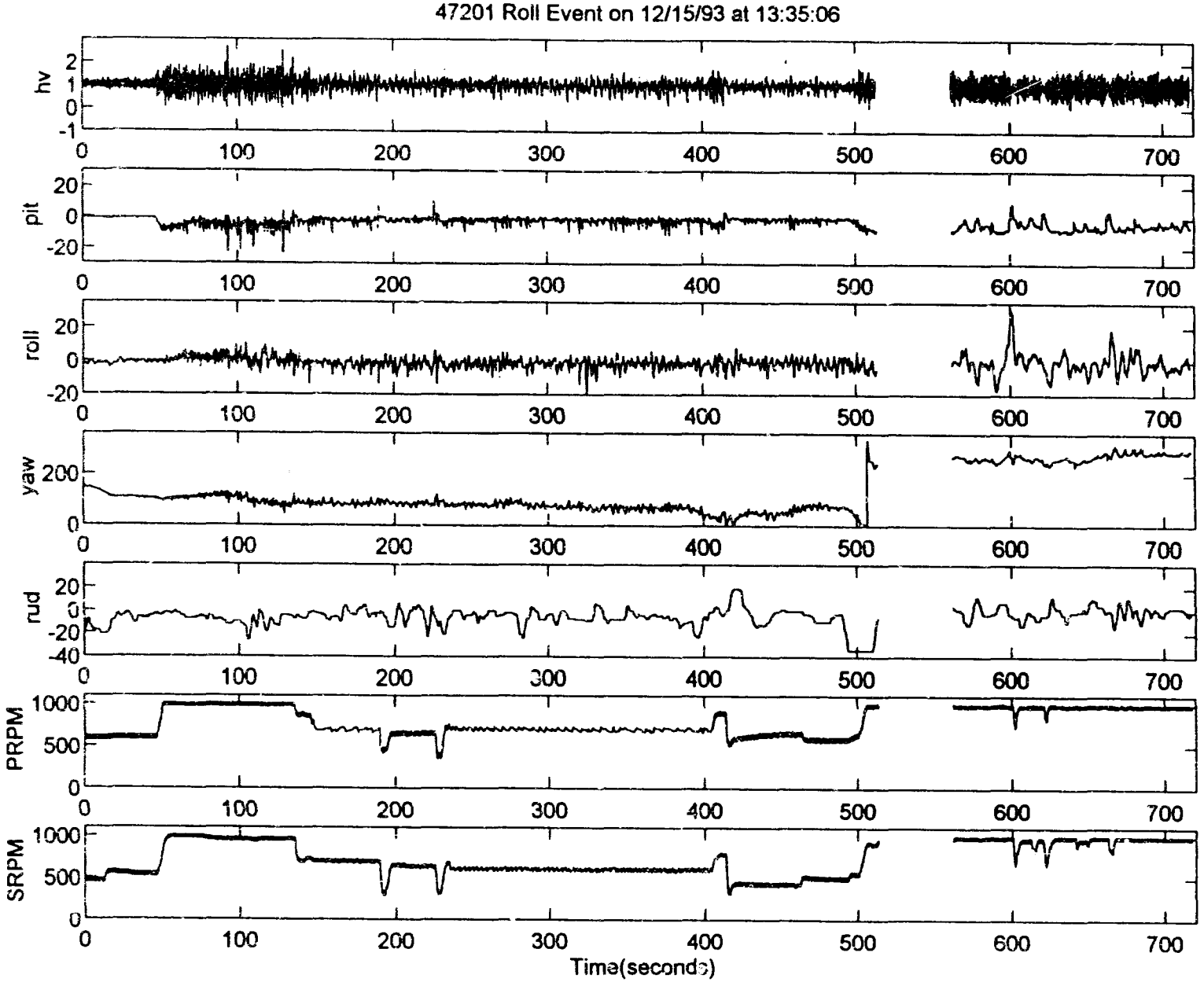


Figure A-2. 47201 Event Summary Plot (12 minutes)

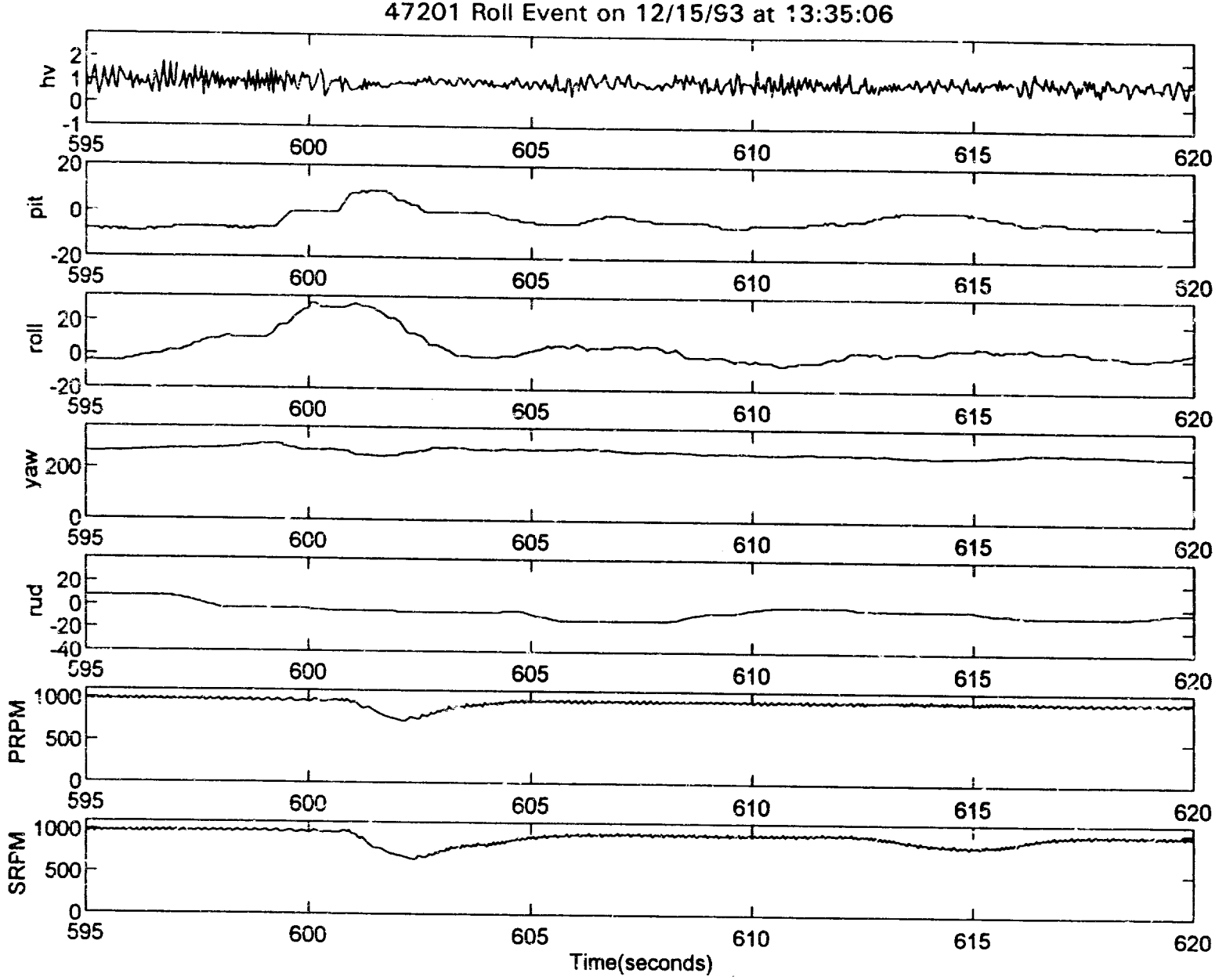


Figure A-3. 47201 Event Summary Plot (25 seconds)

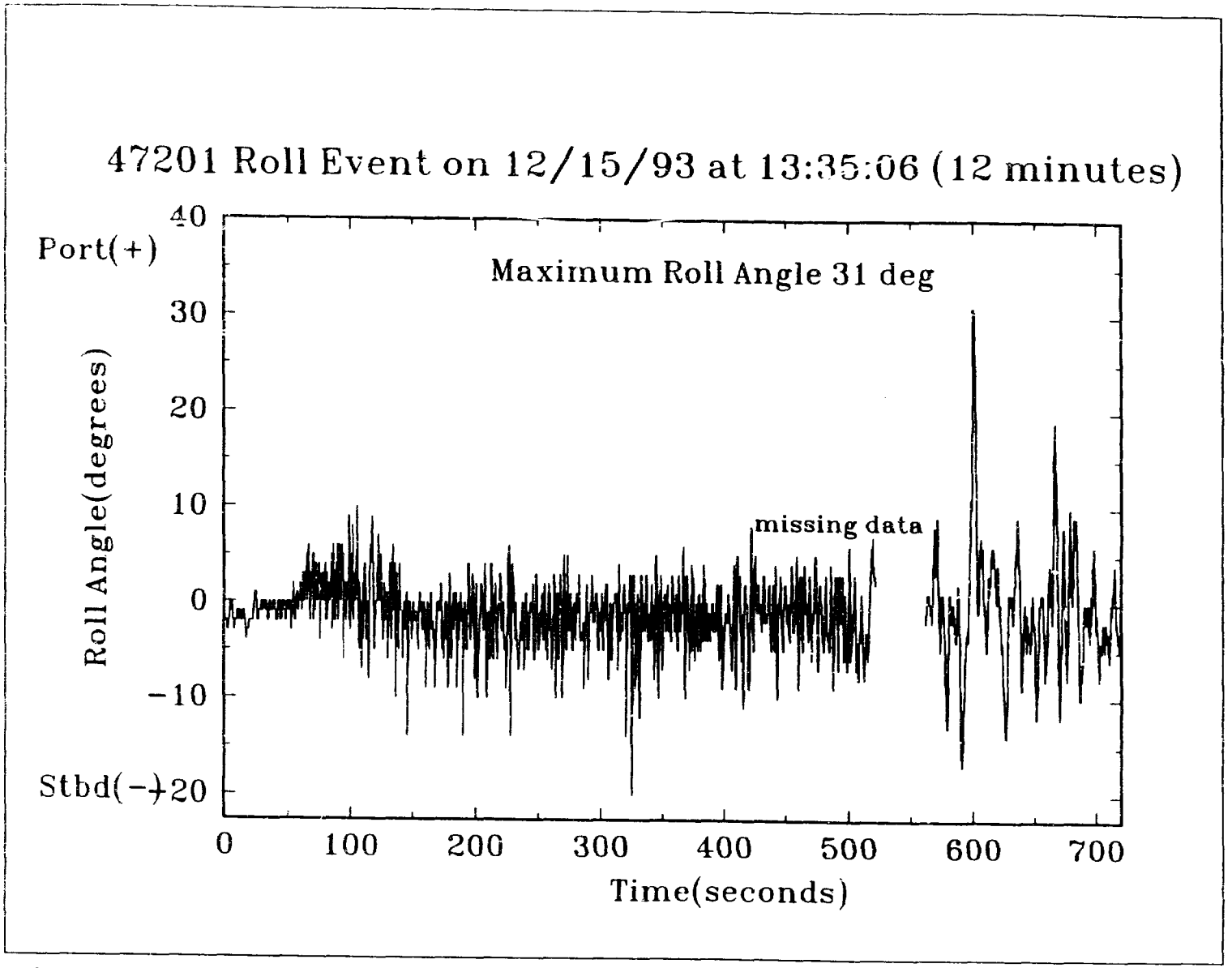


Figure A-4. 47201 Roll Data (12 minutes)

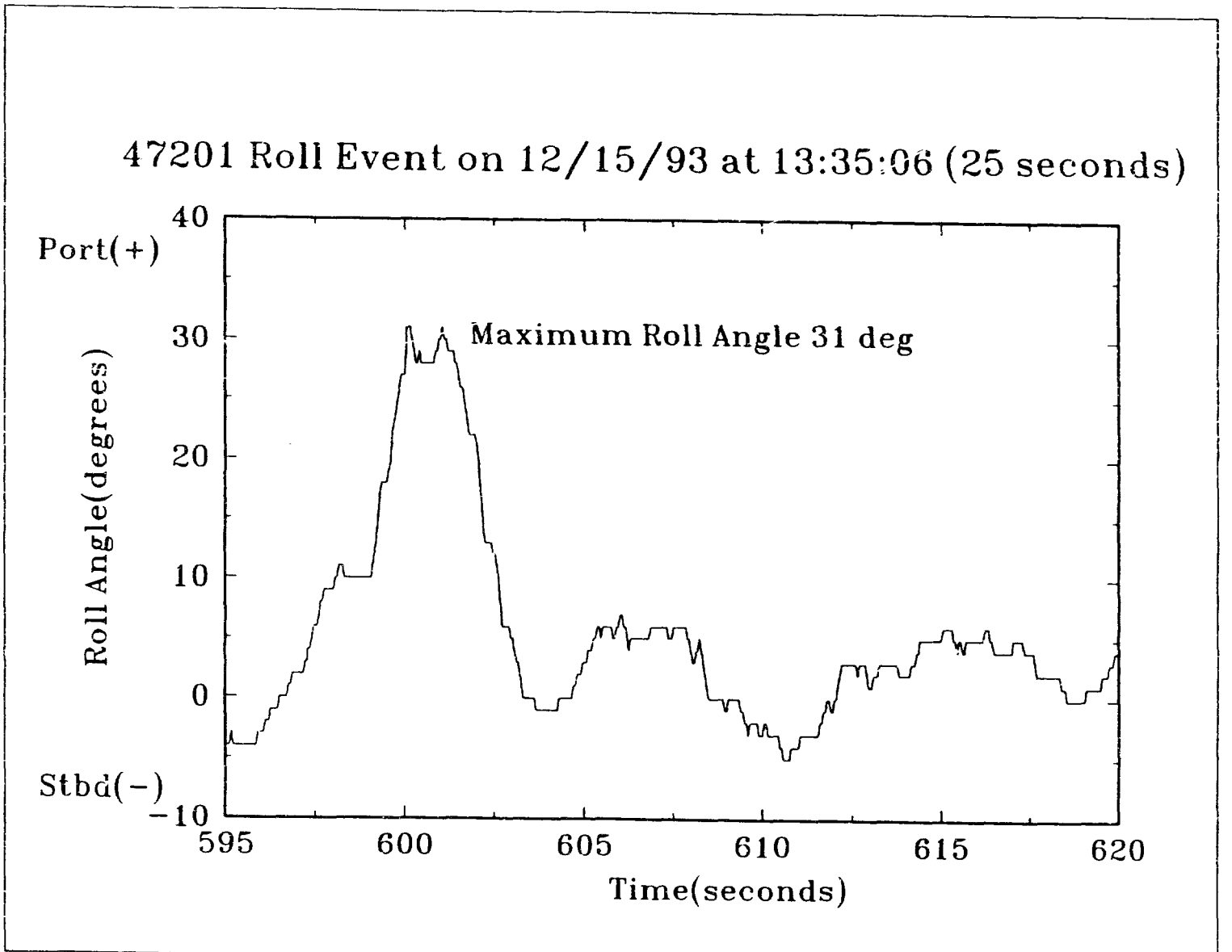


Figure A-5. 47201 Roll Data (25 seconds)

TABLE A-II. 47201 EVENT SUMMARY TABLE

Summary of Data Collected with the MDR

Boat: 47201
Date: 18 FEB 94
Dock Departure (Shore-tie Disconnected): 7:23
Time of Event: 13:33:11
Location: 38.56.97N, 07453.46W
Maximum Roll Angle Detected: 30 degrees
Time Spent Past 90 Degrees: N.A.
Time Spent Past 45 Degrees: N.A.

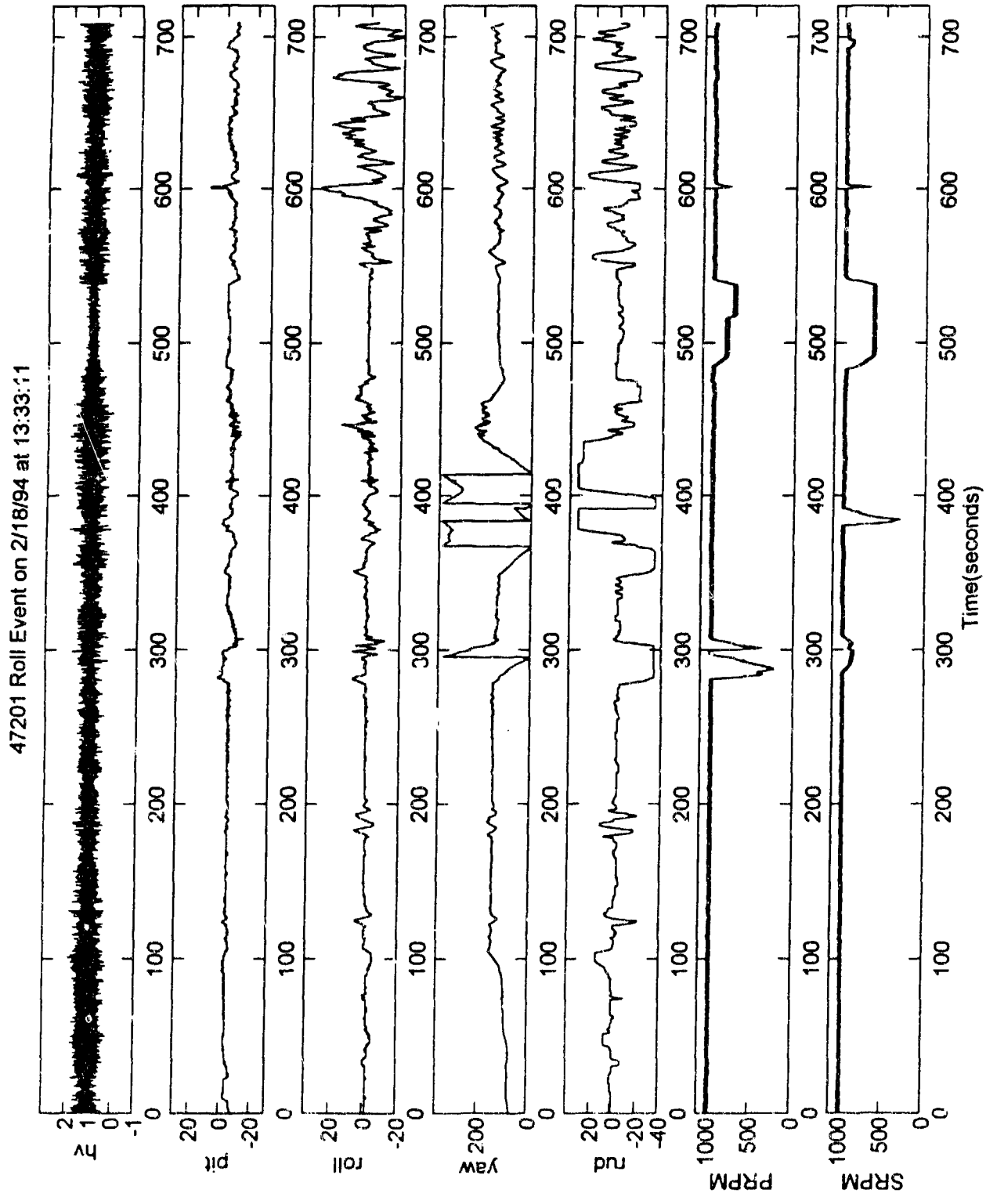


Figure A-6. 47201 Event Summary Plot (12 minutes)

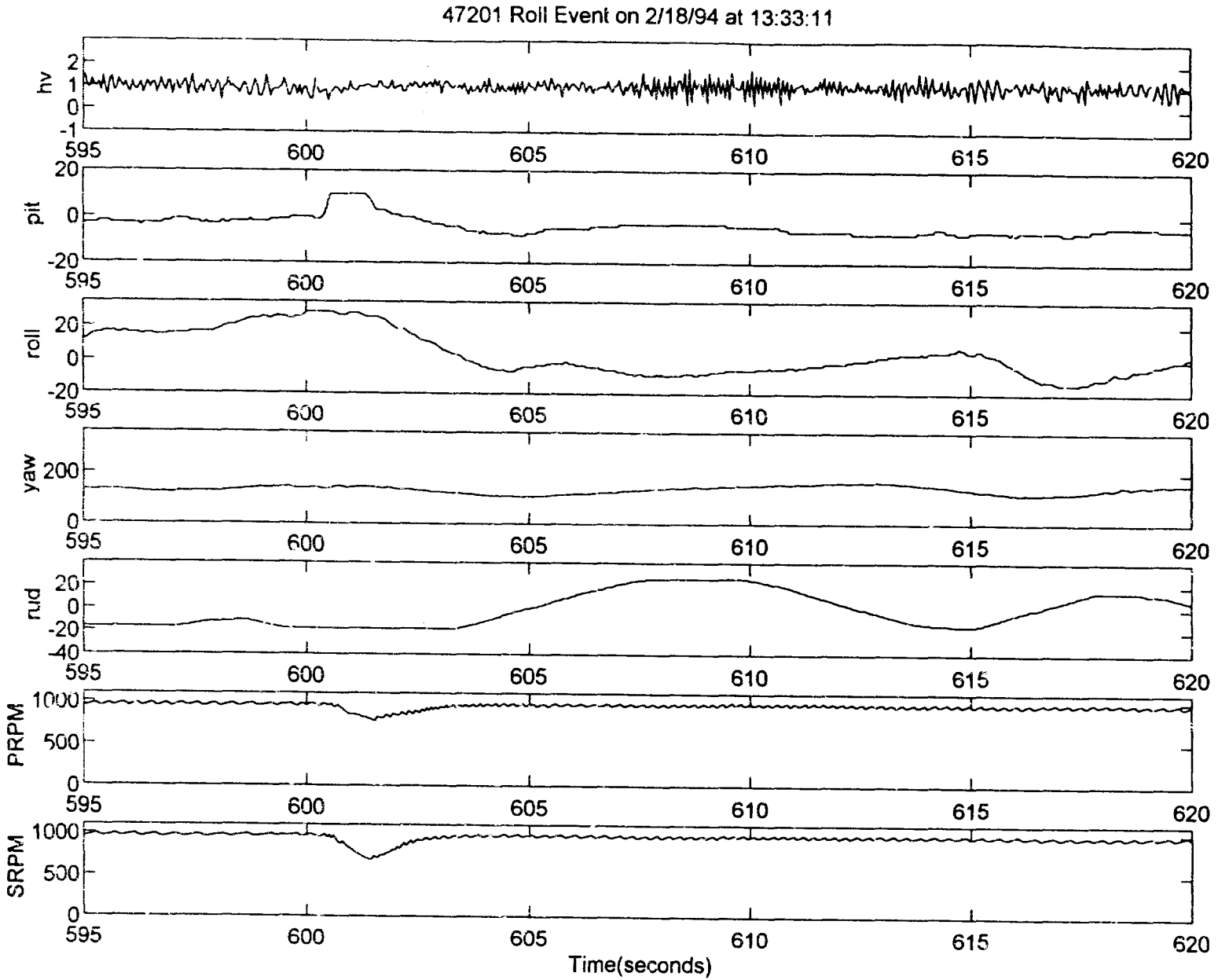


Figure A-7. 47201 Event Summary Plot (25 seconds)

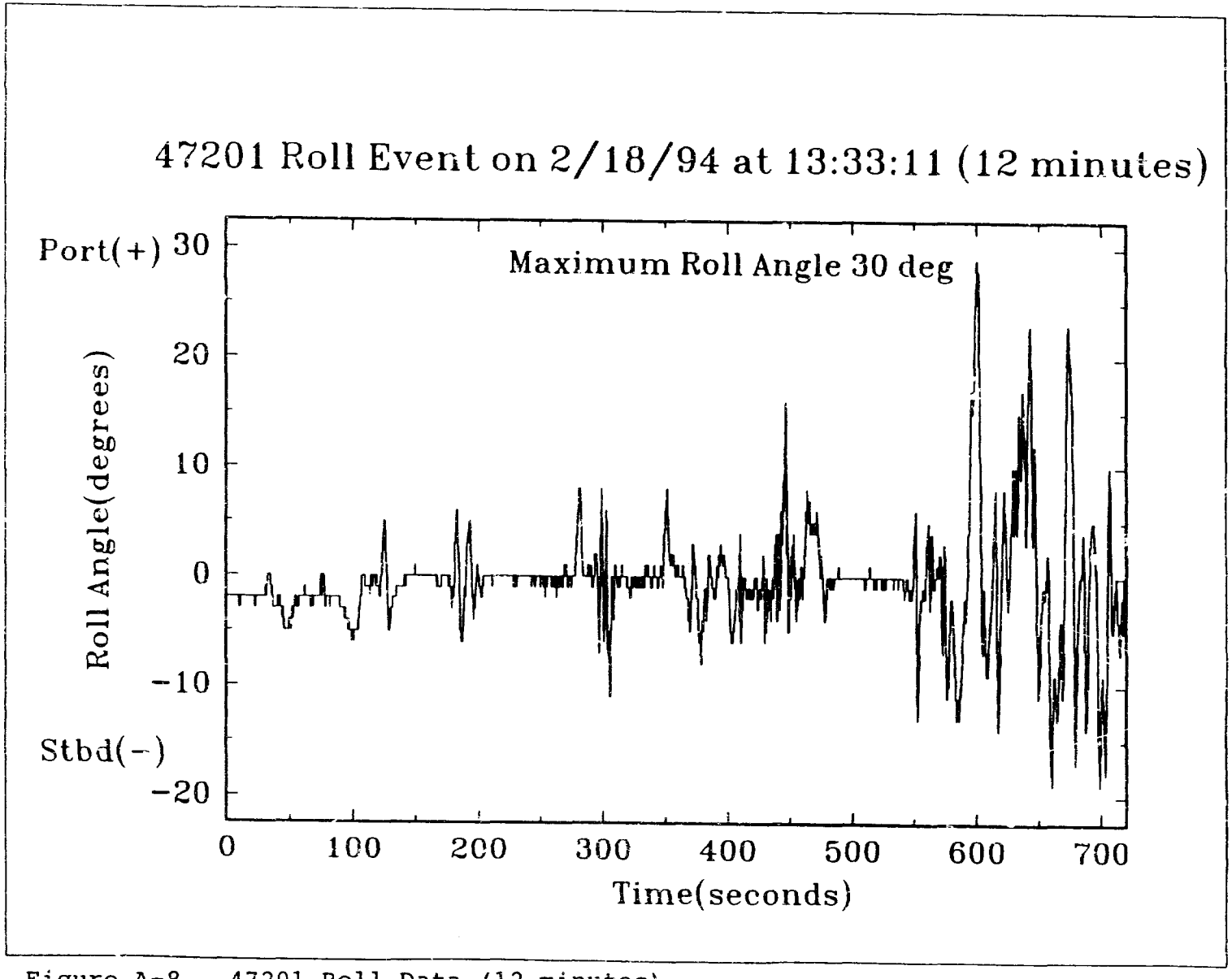


Figure A-8. 47201 Roll Data (12 minutes)

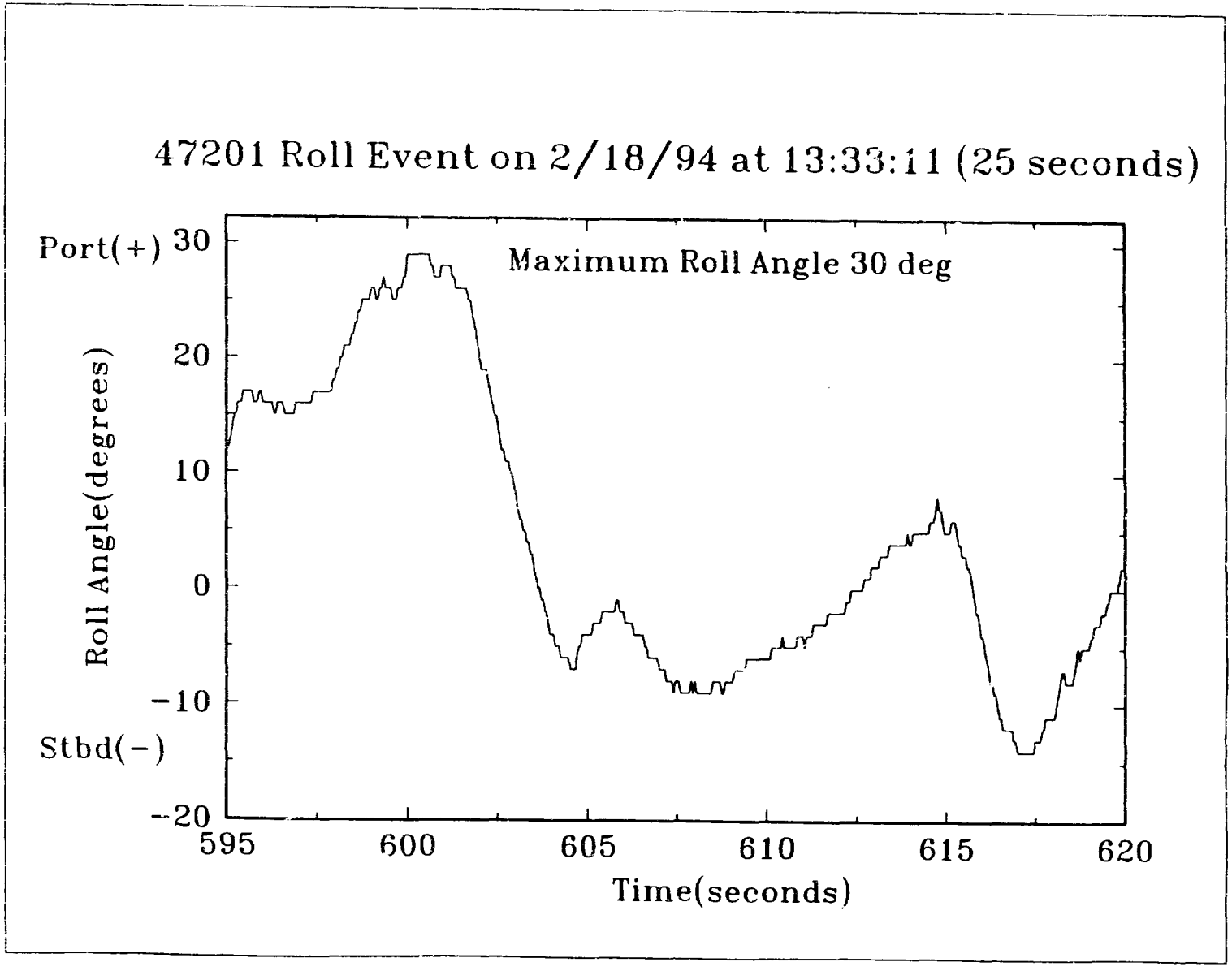


Figure A-9. 47201 Roll Data (25 seconds)

TABLE A-III. 47201 EVENT SUMMARY TABLE

Summary of Data Collected with the MDR

Boat: 47201
Date: 03 MAR 94
Dock Departure (Shore-tie Disconnected): Not Recorded
Time of Event: 10:38:59
Location: Not Recorded
Maximum Roll Angle Detected: 53 degrees
Time Spent Past 90 Degrees: N.A.
Time Spent Past 45 Degrees: 3.6 seconds
Stbd Engine RPM:
- Before Event - 1900 RPM
- During Event - decreasing rapidly
- After Event - engine stalled for about 1 minute

Port Engine RPM:
- Before Event - 1900 RPM
- During Event - decreasing rapidly
- After Event - 900 RPM

Rudder Angle:
- Before Event - -2 degrees
- During Event - 4 degrees
- After Event - changed rapidly to 16 degrees to port

Heading:
- Before Event - 310 degrees
- After Event - 240 degrees

Pitch: 35 degrees (bow down)

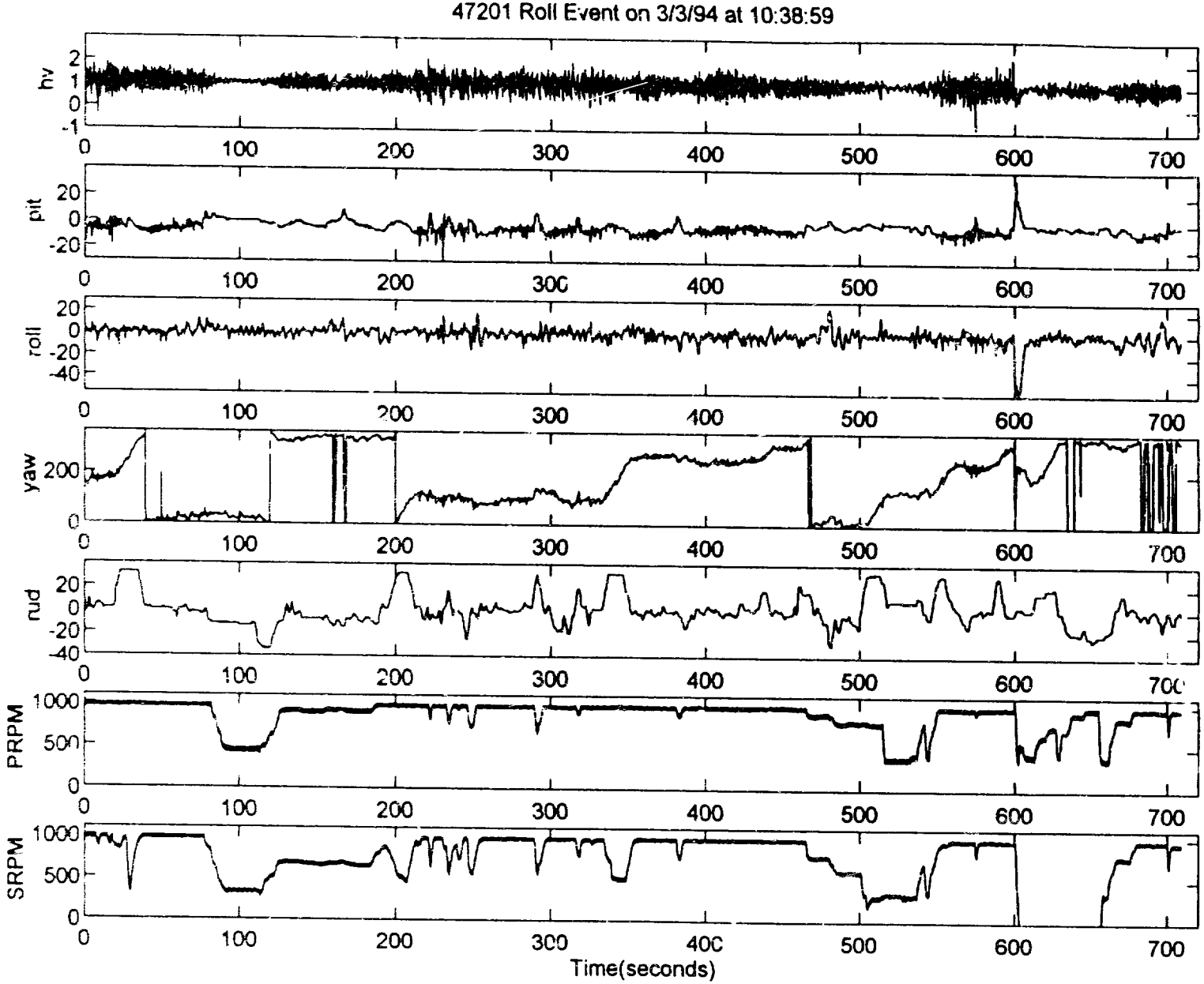


Figure A-10. 47201 Event Summary Plot (12 minutes)

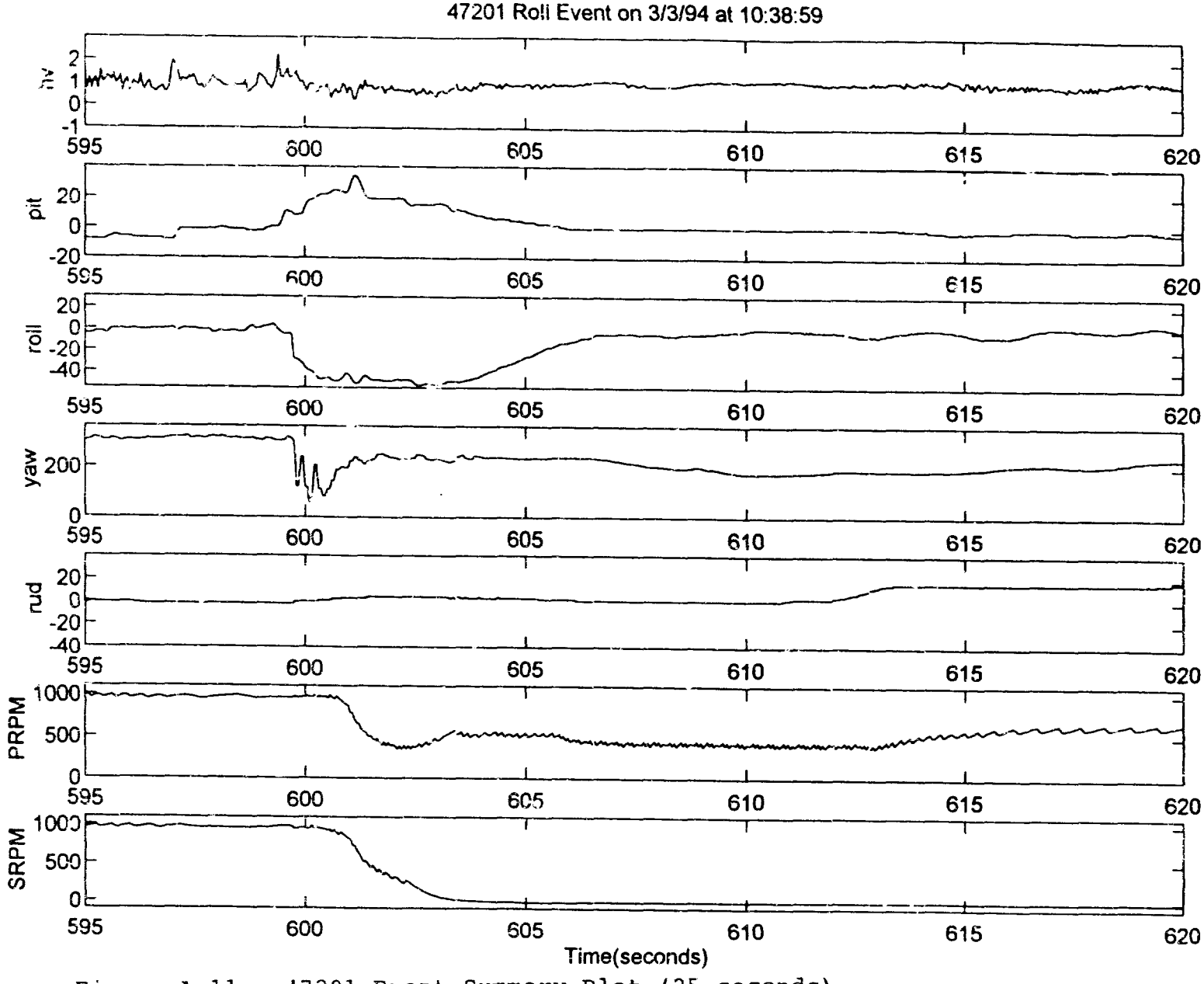


Figure A-11. 47201 Event Summary Plot (25 seconds)

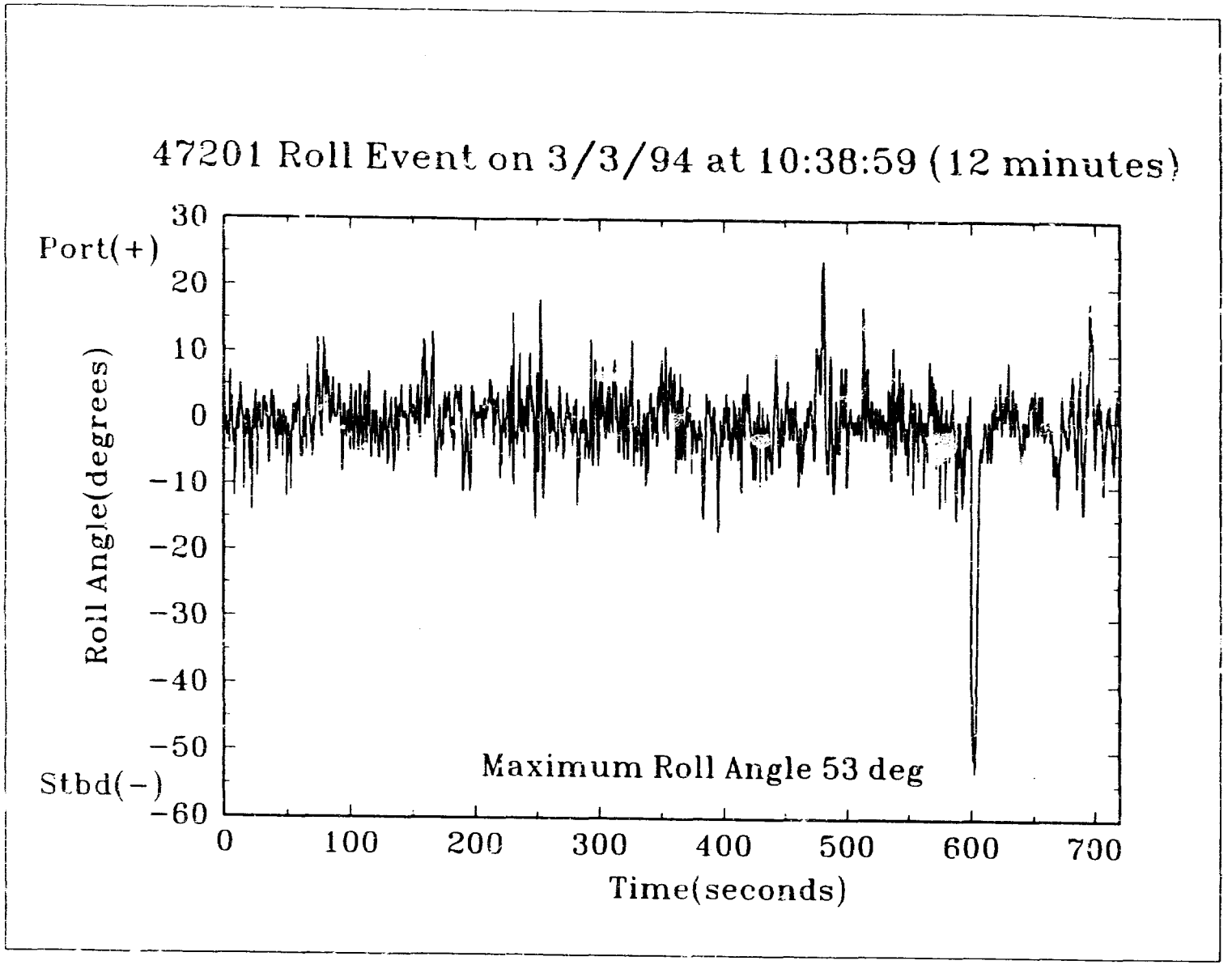


Figure A-12. 47201 Roll Data (12 minutes)

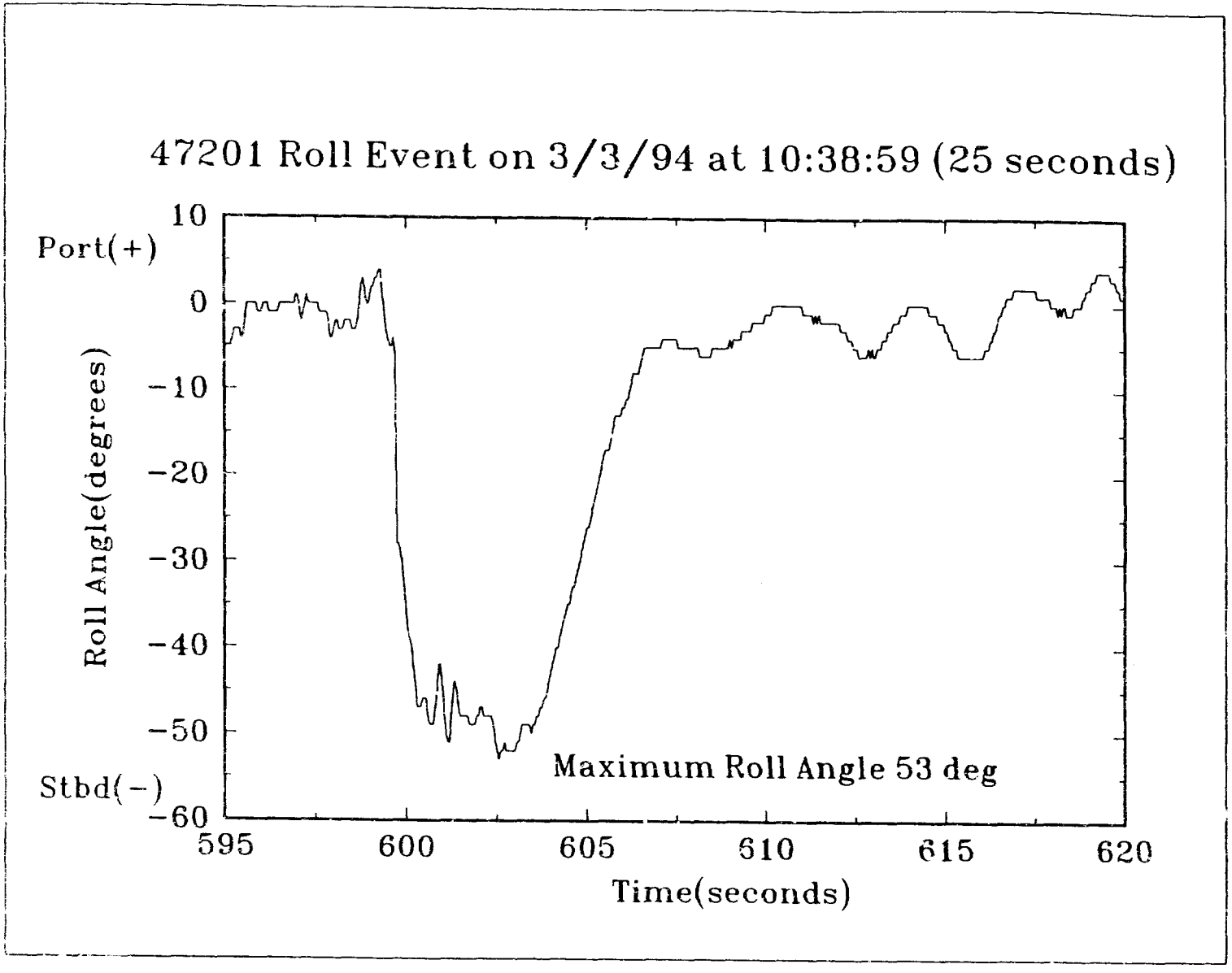


Figure A-13. 47201 Roll Data (25 seconds)

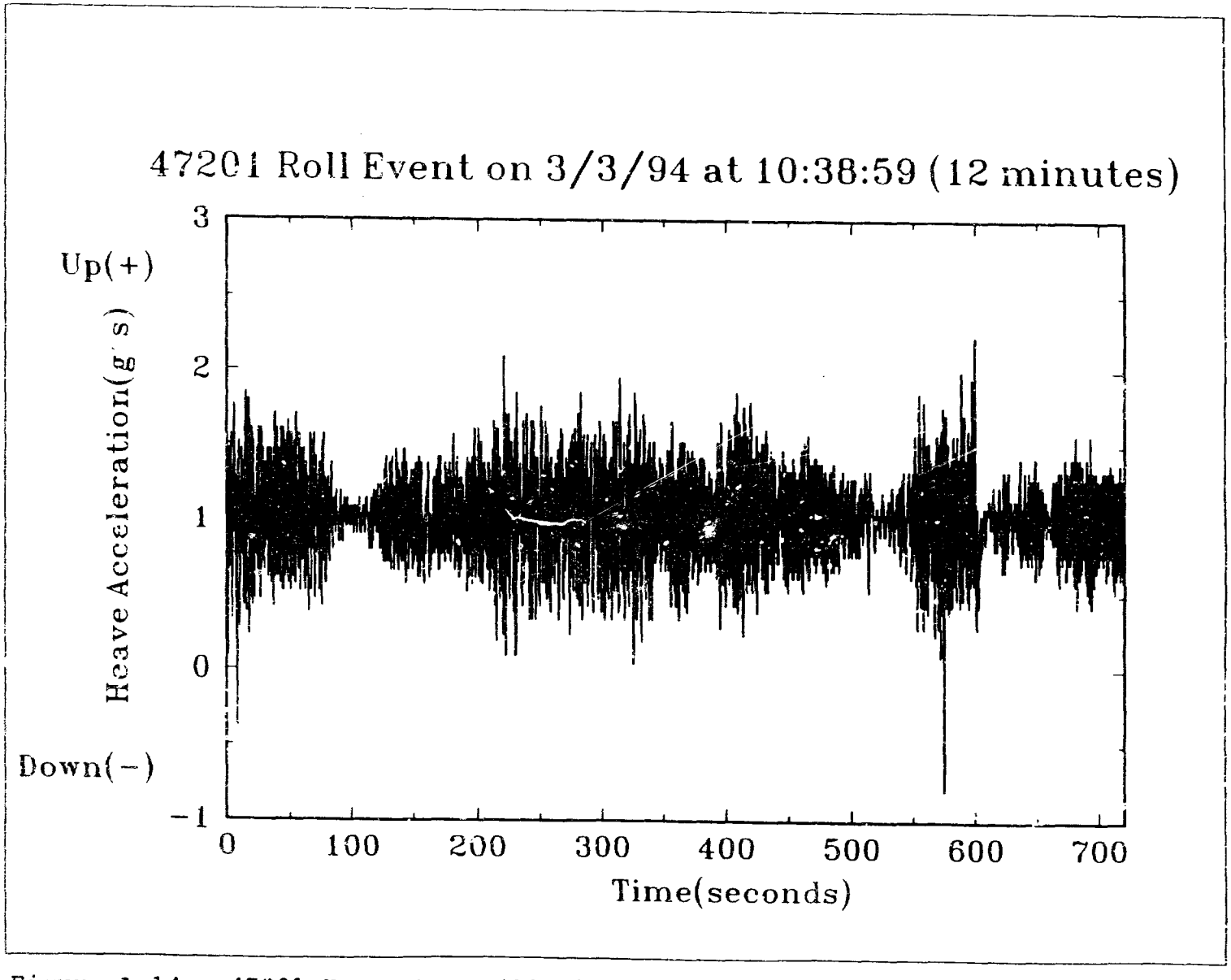


Figure A-14. 47201 Heave Data (12 minutes)

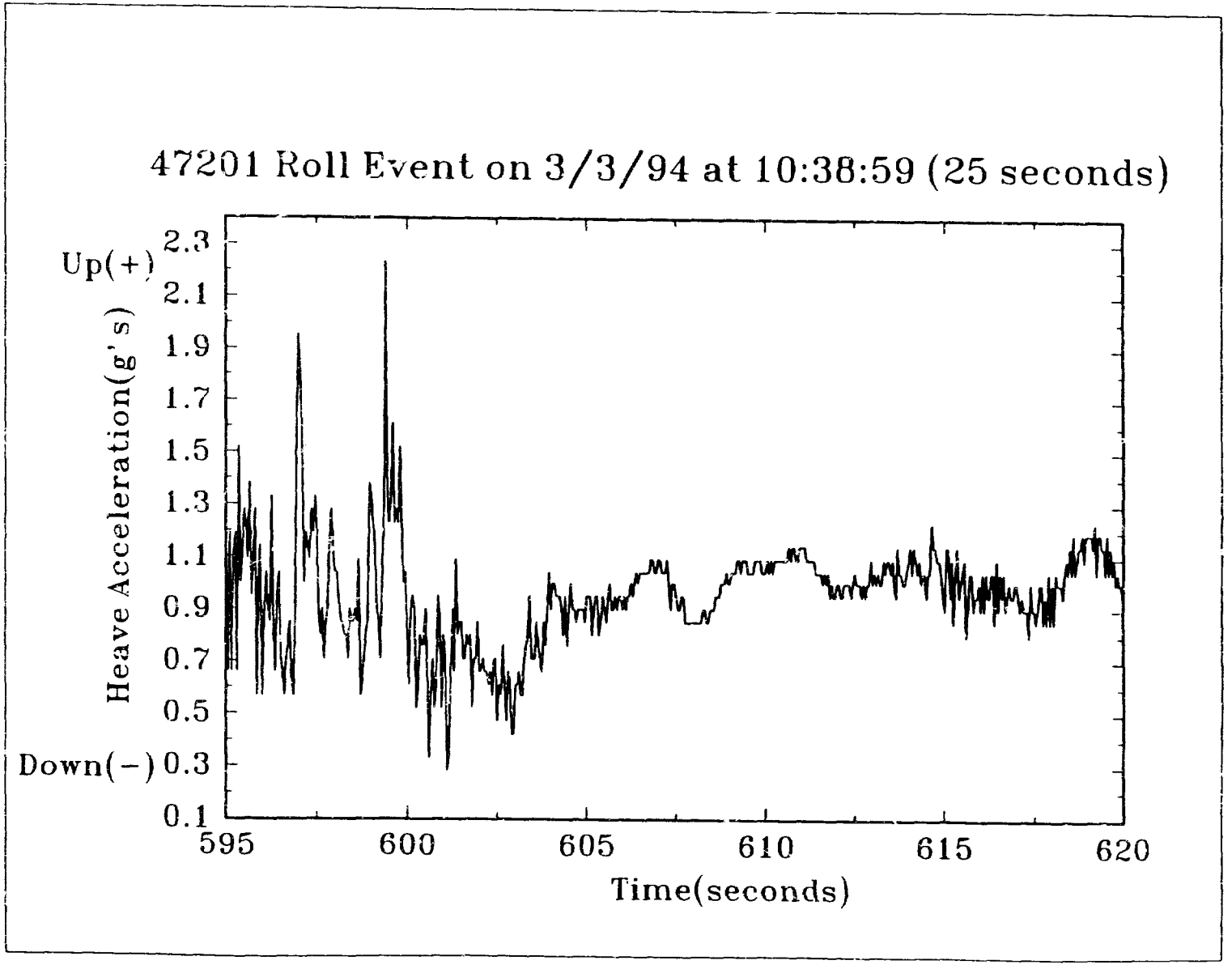


Figure A-15. 47201 Heave Data (25 seconds)

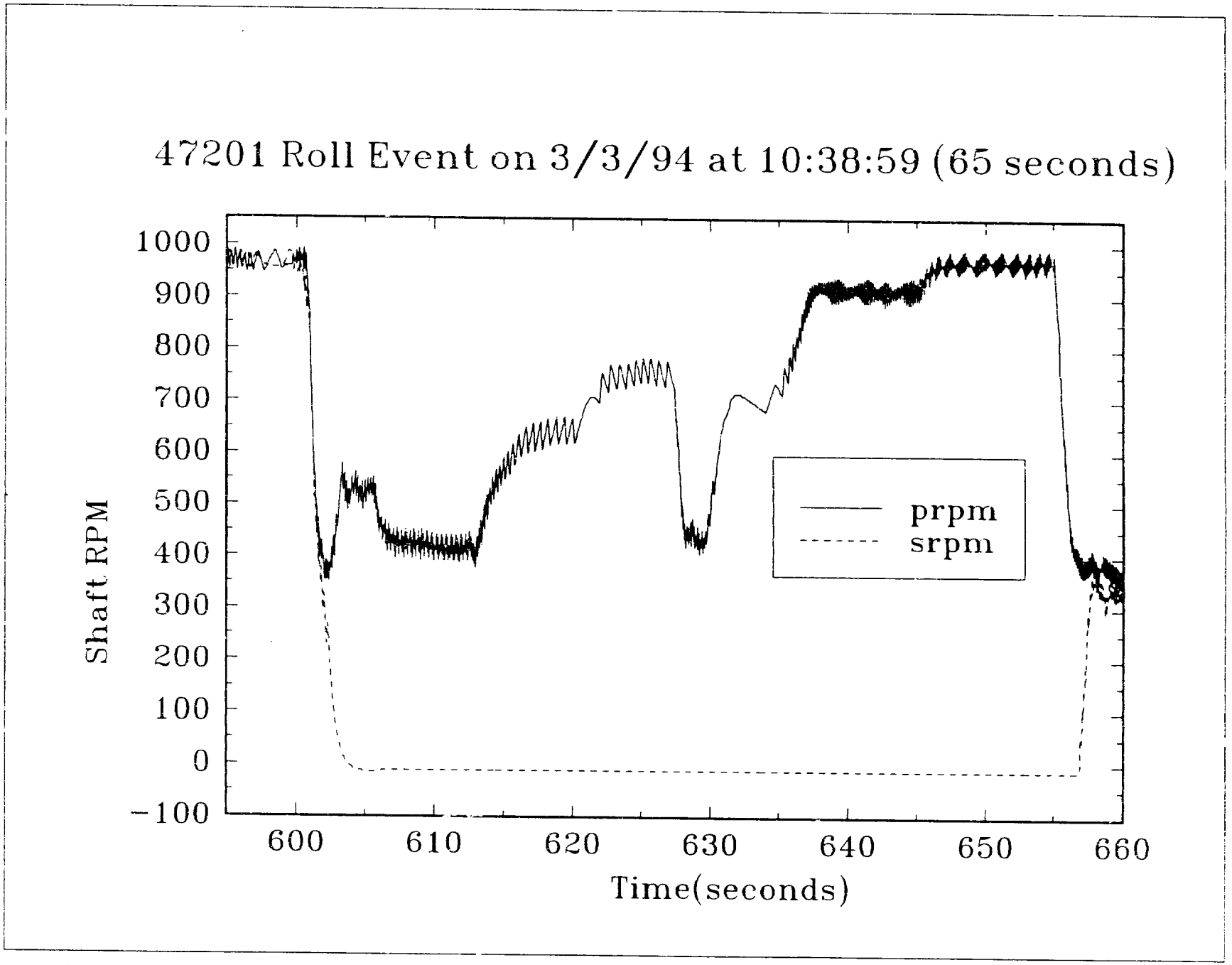


Figure A-16. 47201 RPM Data (65 seconds)

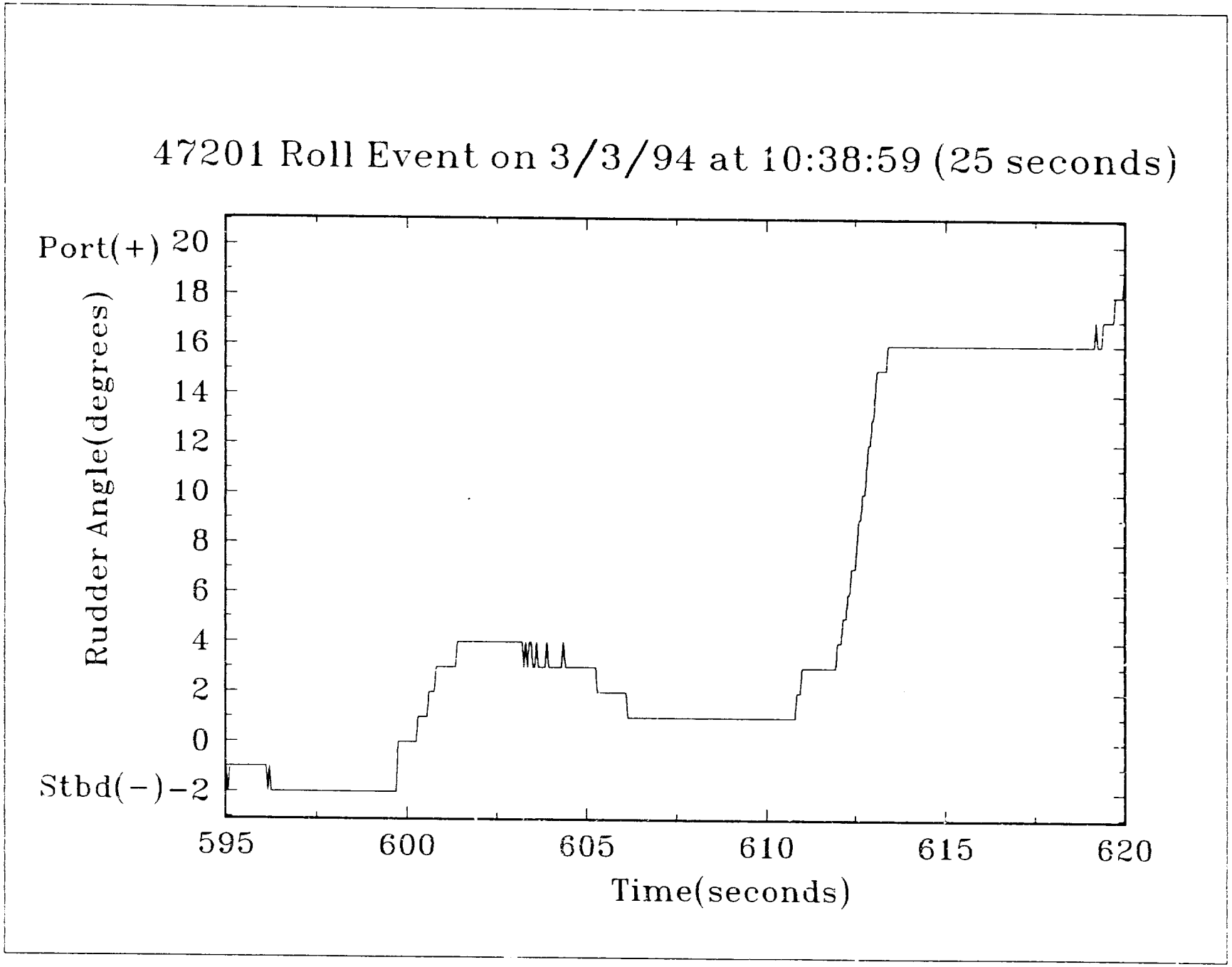


Figure A-17. 47201 Rudder Data (25 seconds)

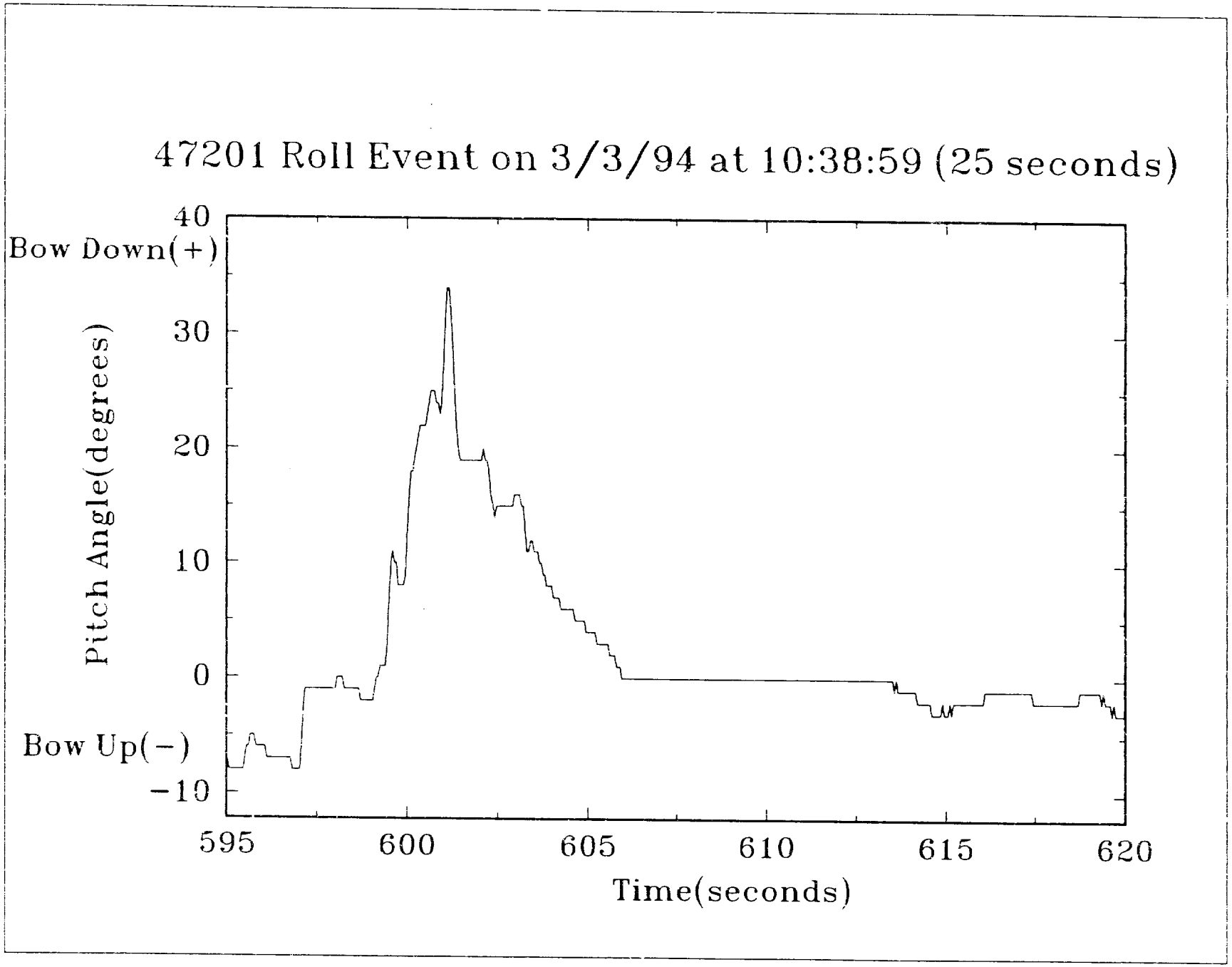
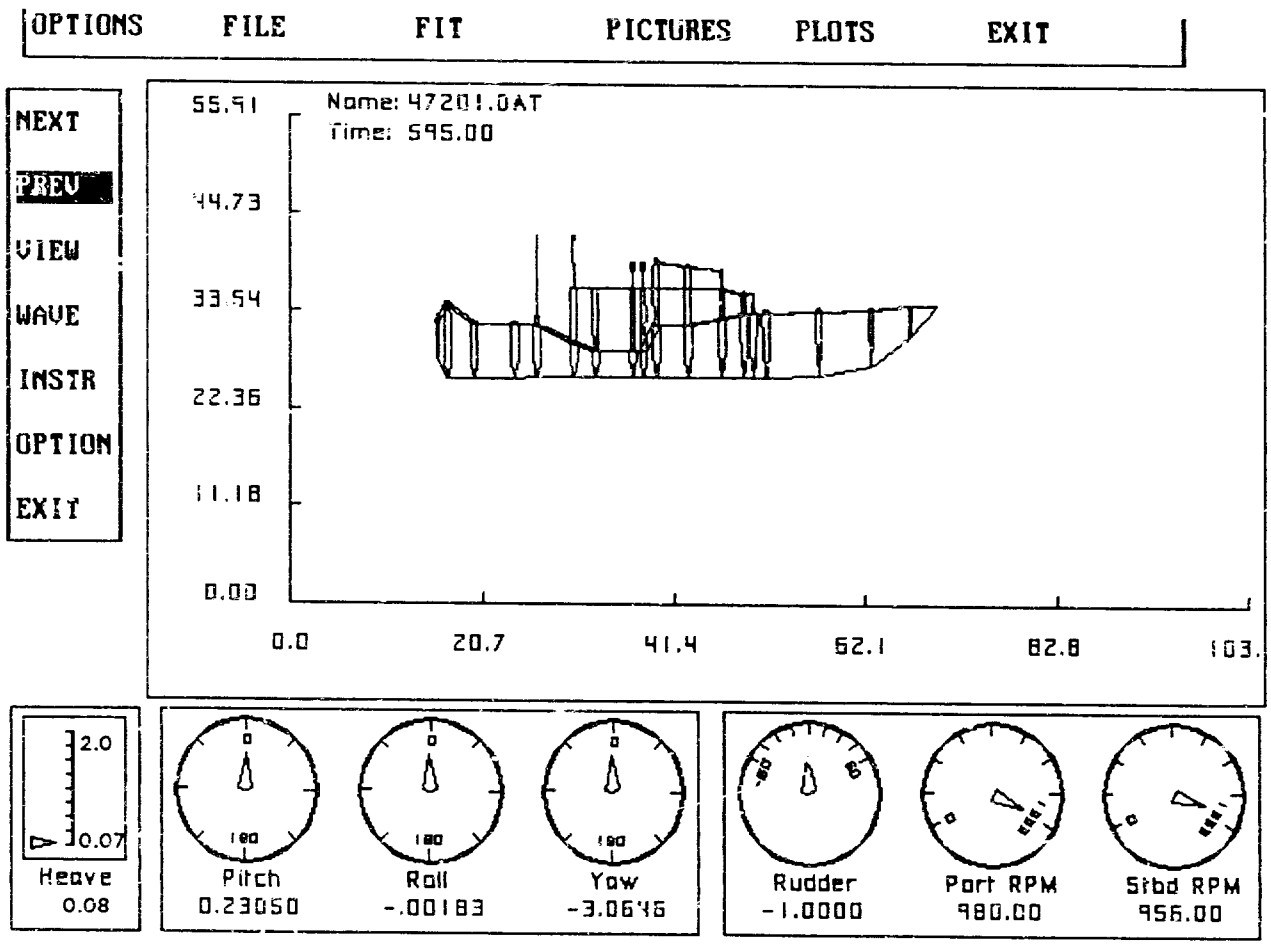


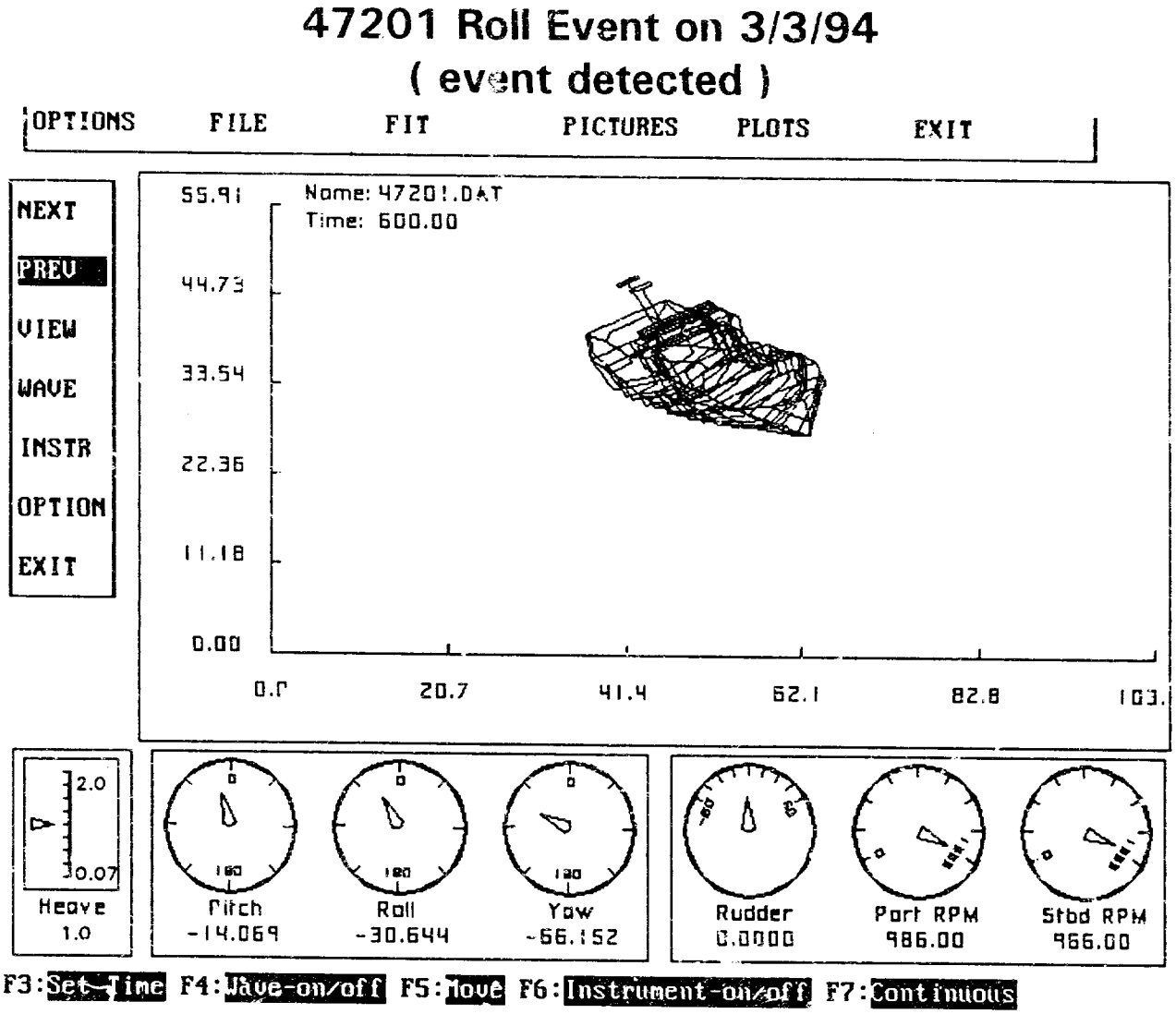
Figure A-18. 47201 Pitch Angle Data (25 seconds)

47201 Roll Event on 3/3/94
(-5 seconds)



At 5 seconds before the event both engines are operating near cruising speed. The 47201 experienced some higher than normal heave accelerations just prior to the event trigger.

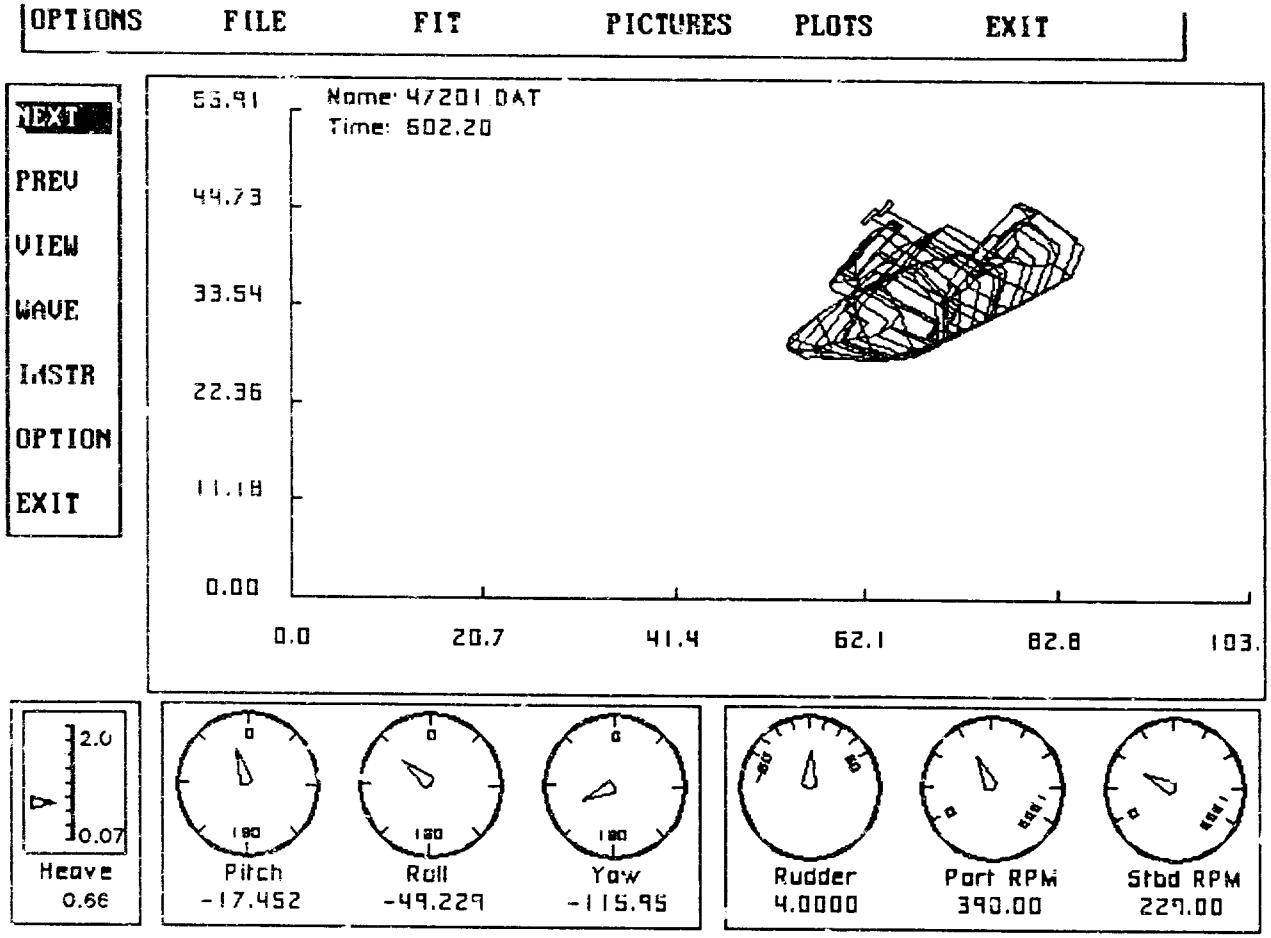
Figure A-19. 47201 Roll Event (-5 seconds)



At the event trigger (threshold was set to 30 degrees) the 47201 rolls to starboard while beginning a steady bow down pitch rate to a maximum of 35 degrees (note that pitch data was low-pass filtered to 0.5 Hz). RPM levels have not changed.

Figure A-20. 47201 Roll Event (event detected)

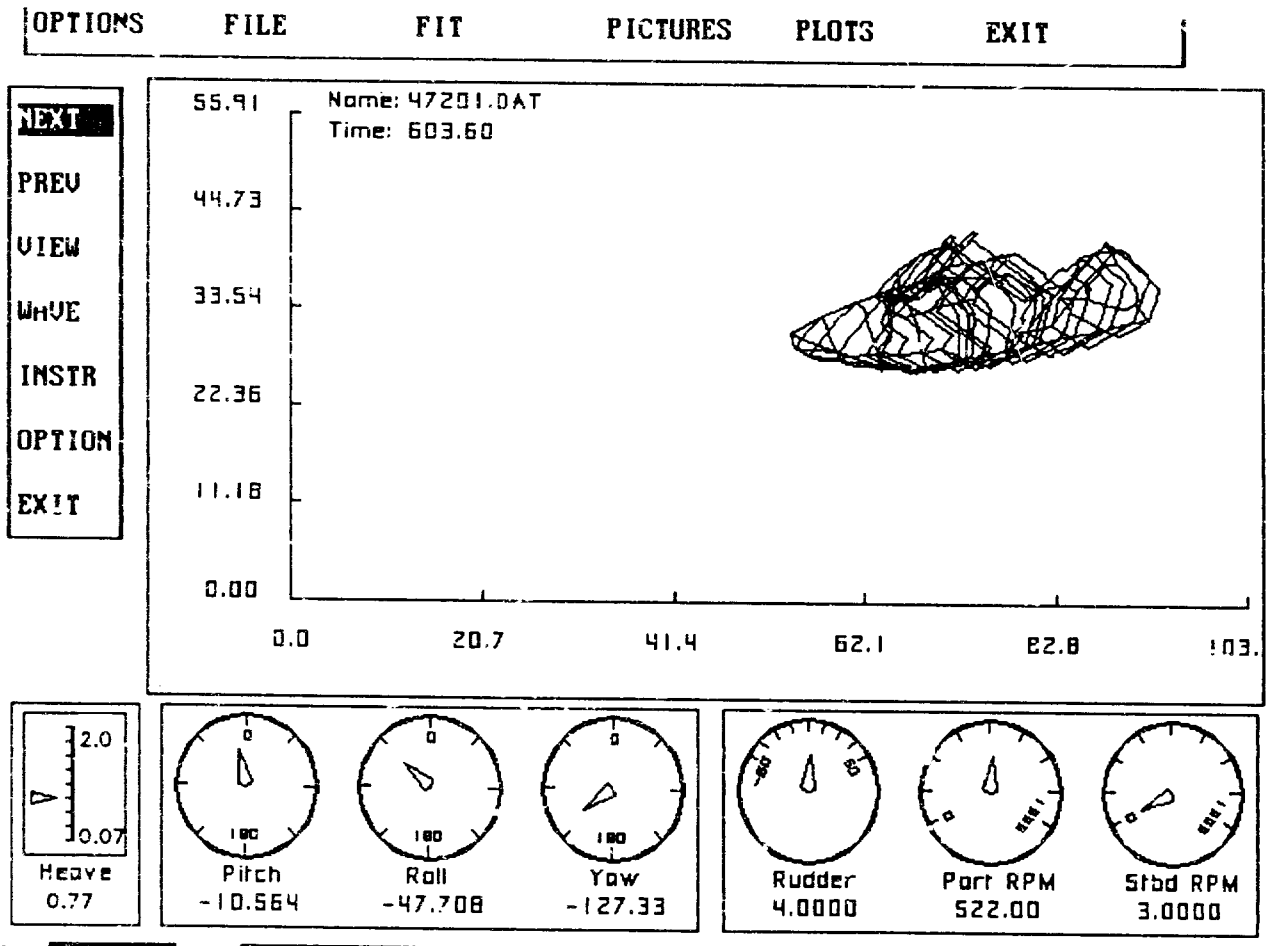
47201 Roll Event on 3/3/94
(+ 2 seconds)



At 2 seconds after the event and after the 47201 is near 50 degrees to starboard the starboard engine rapidly begins falling to 0 RPM.

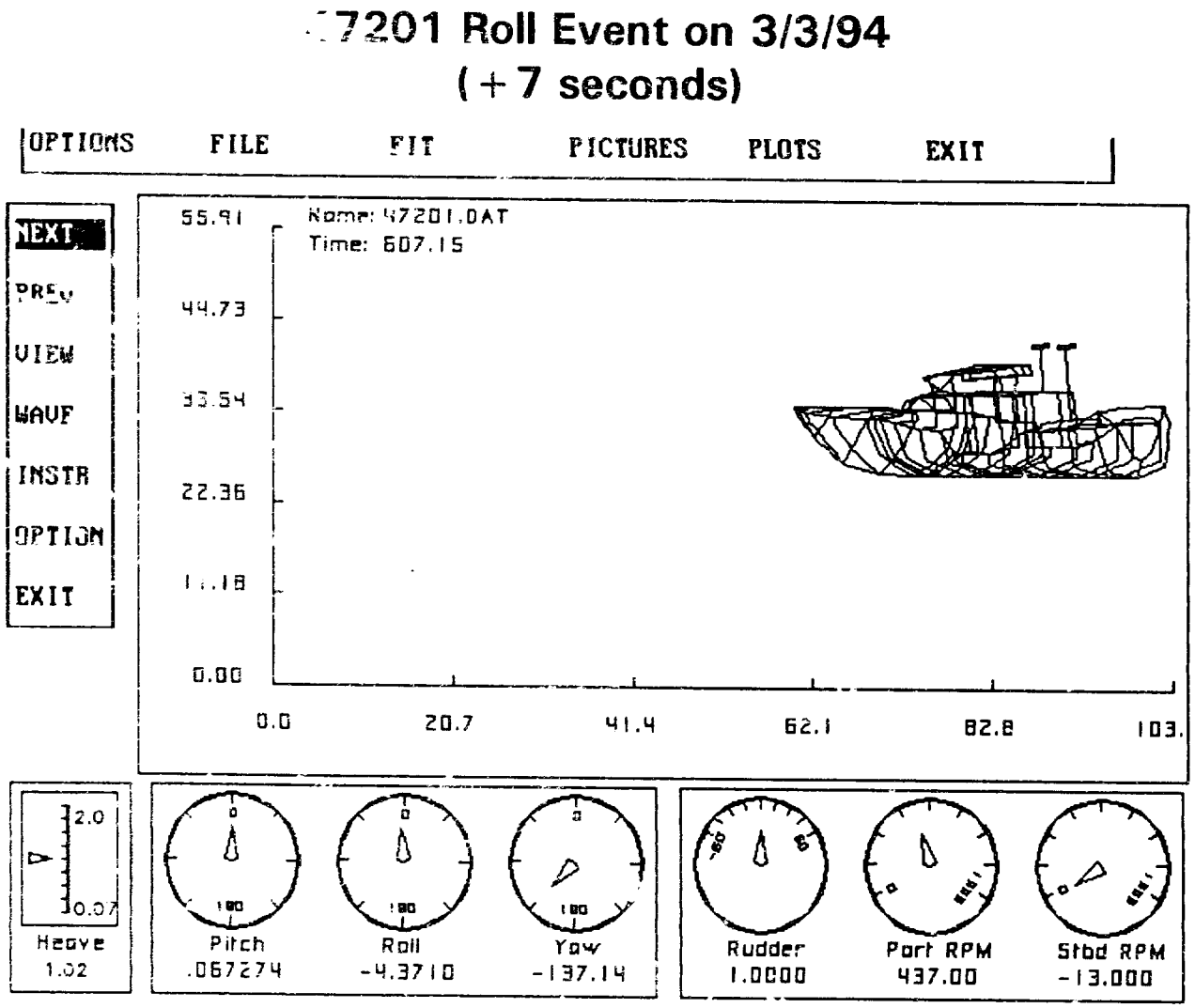
Figure A-21. 47201 Roll Event (+2 seconds)

47201 Roll Event on 3/3/94
(+4 seconds)



At 4 seconds after the event the starboard egine has reached 0 RPM. It takes approximately 53 seconds for the the starboard engine to re-start.

Figure A-22. 47201 Roll Event (+4 seconds)



At 7 seconds after the event the 47201 returns to an even keel.

Figure A-23. 47201 Roll Event (+7 seconds)

TABLE A-IV. 47201 EVENT SUMMARY TABLE

Summary of Data Collected with the MDR

Boat: 47201
Date: 12 MAY 94
Dock Departure (Shore-tie Disconnected): Not Recorded
Time of Event: 13:43:48
Location: Not Recorded
Maximum Roll Angle Detected: 30 degrees (triggered off a 30 degree roll, but a maximum roll post-event was detected at being 32 degrees.)
Time Spent Past 90 Degrees: N.A.
Time Spent Past 45 Degrees: N.A.

Note: The port RPM tach was not operating during the event.

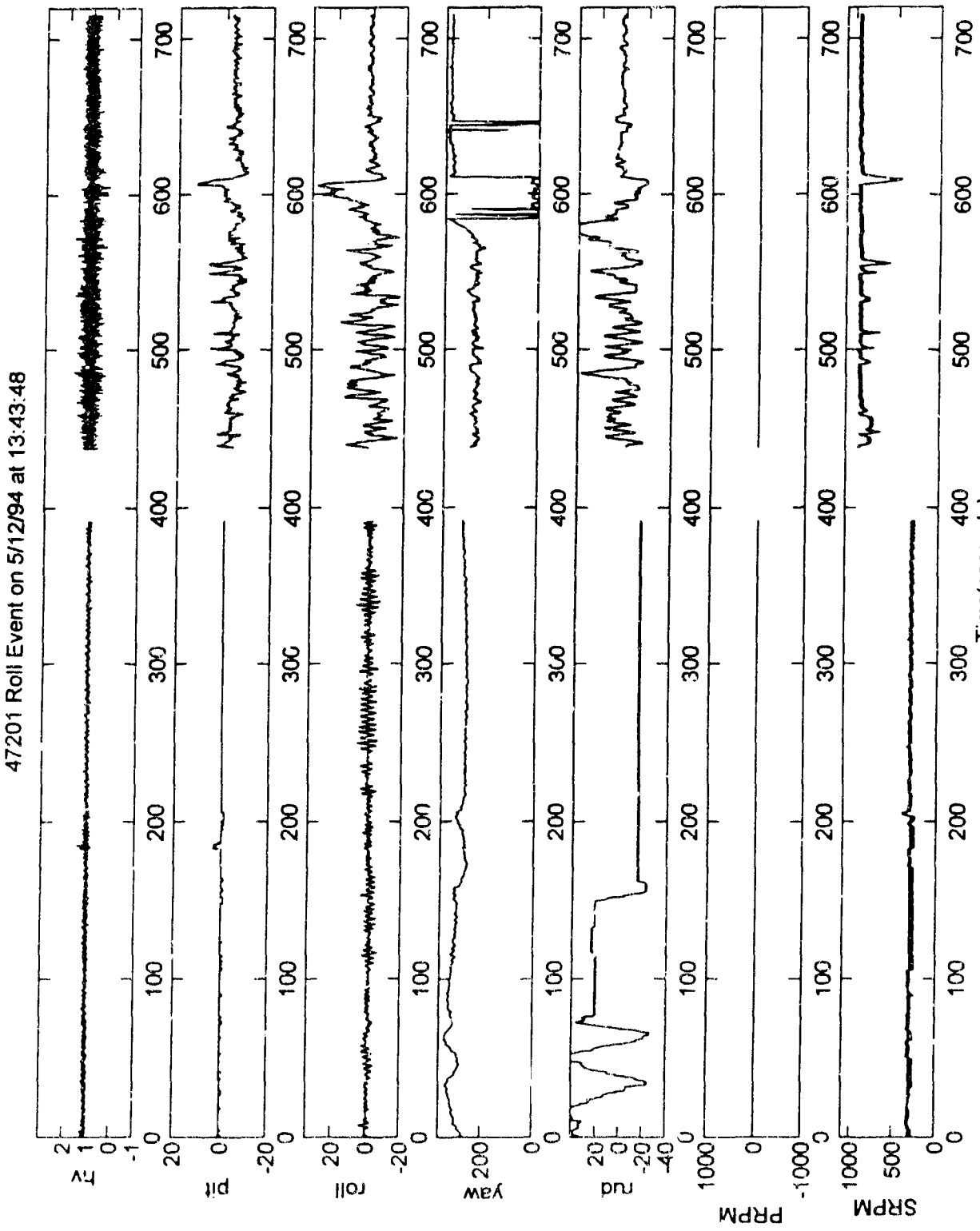


Figure A-24. 47201 Event Summary Plot (12 minutes)

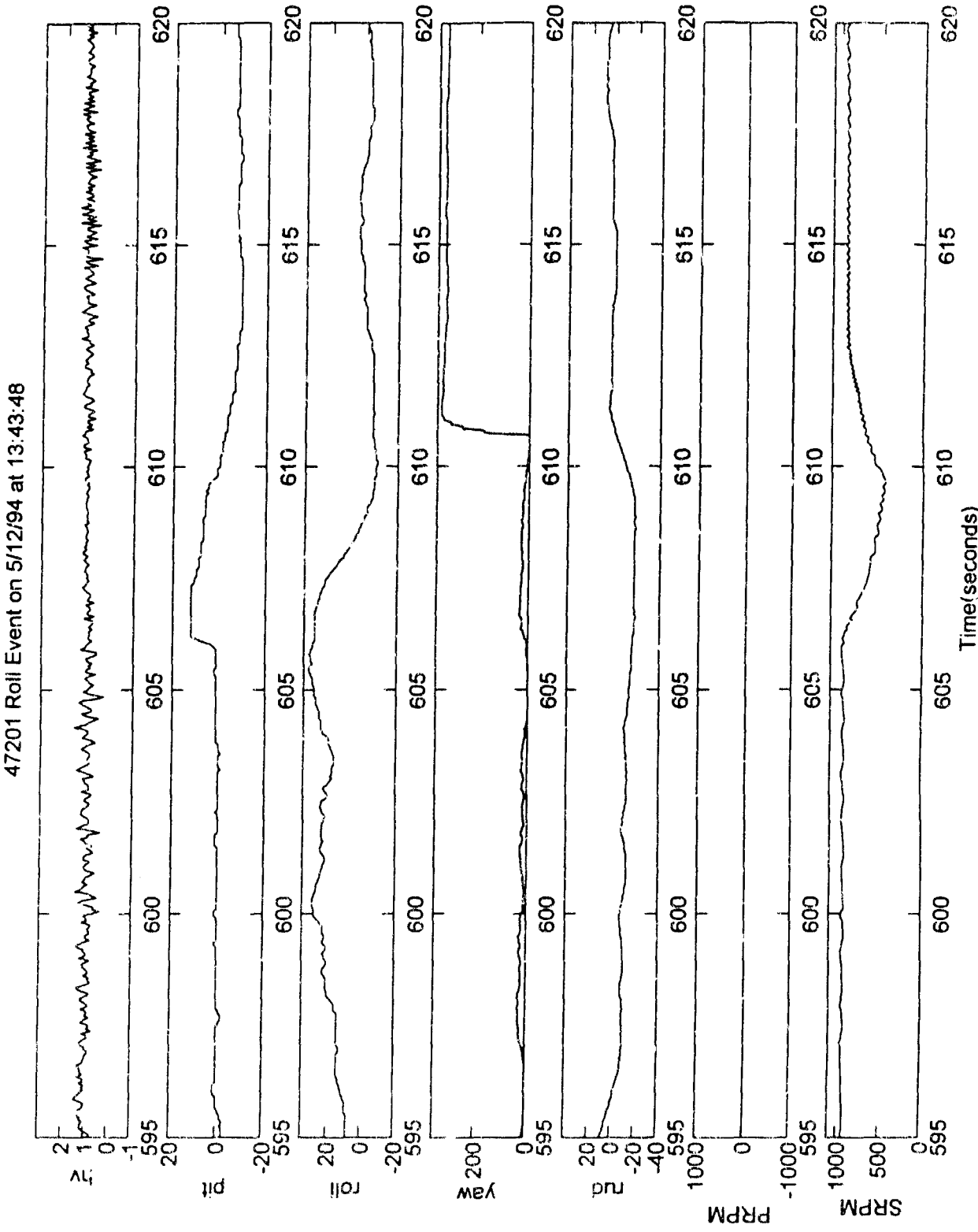


Figure A-25. 47201 Event Summary Plot (25 seconds)

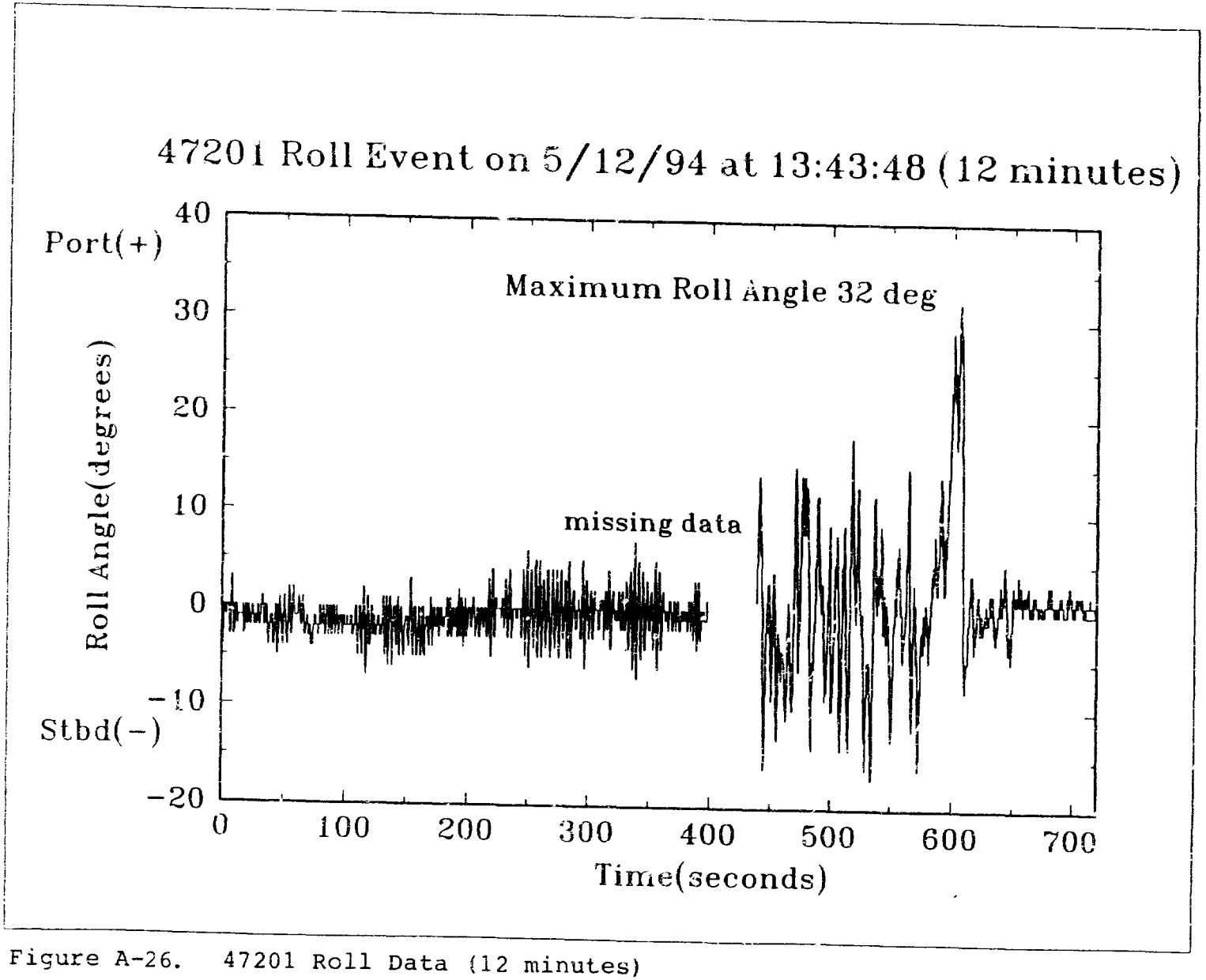


Figure A-26. 47201 Roll Data (12 minutes)

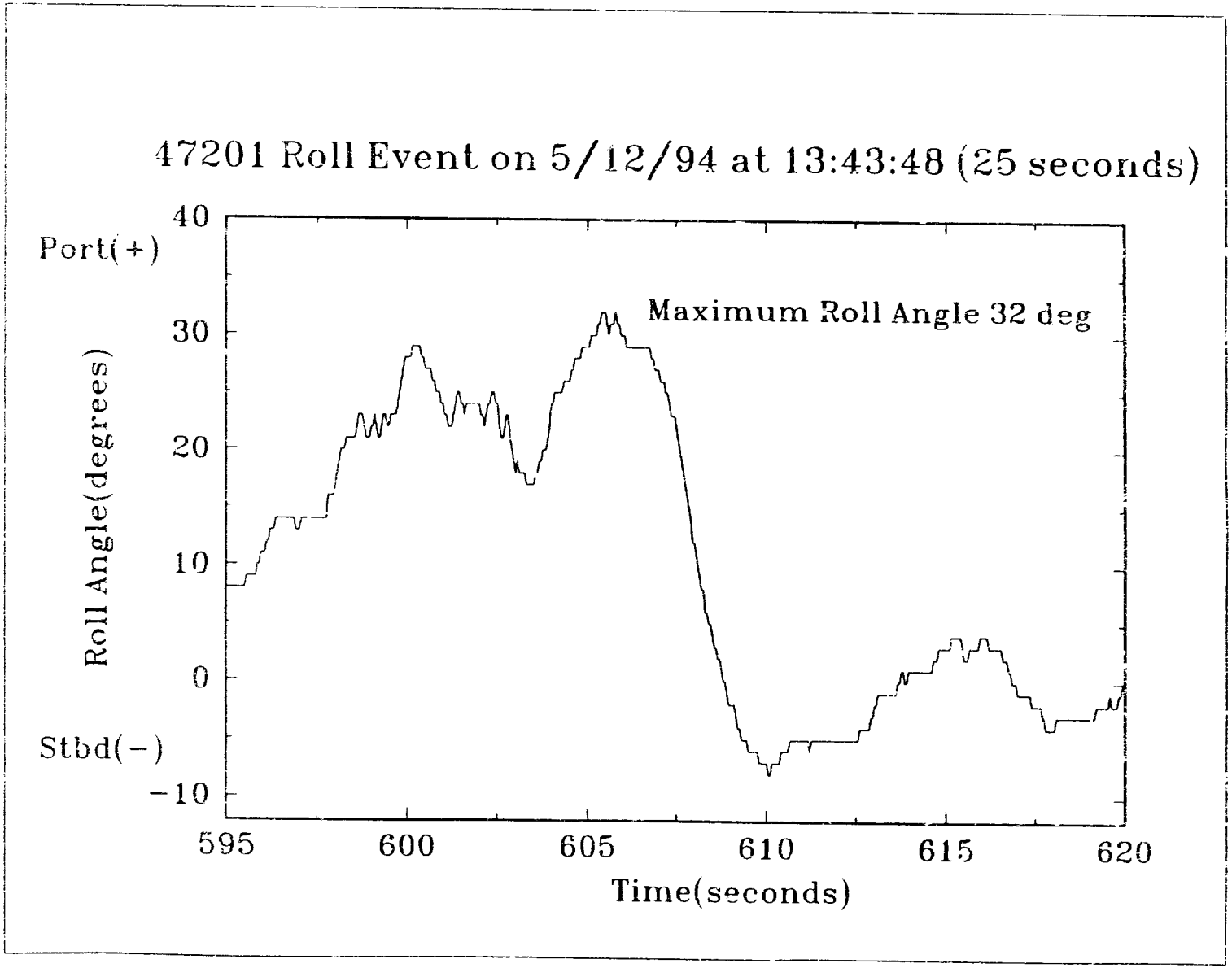


Figure A-27. 47201 Roll Data (25 seconds)

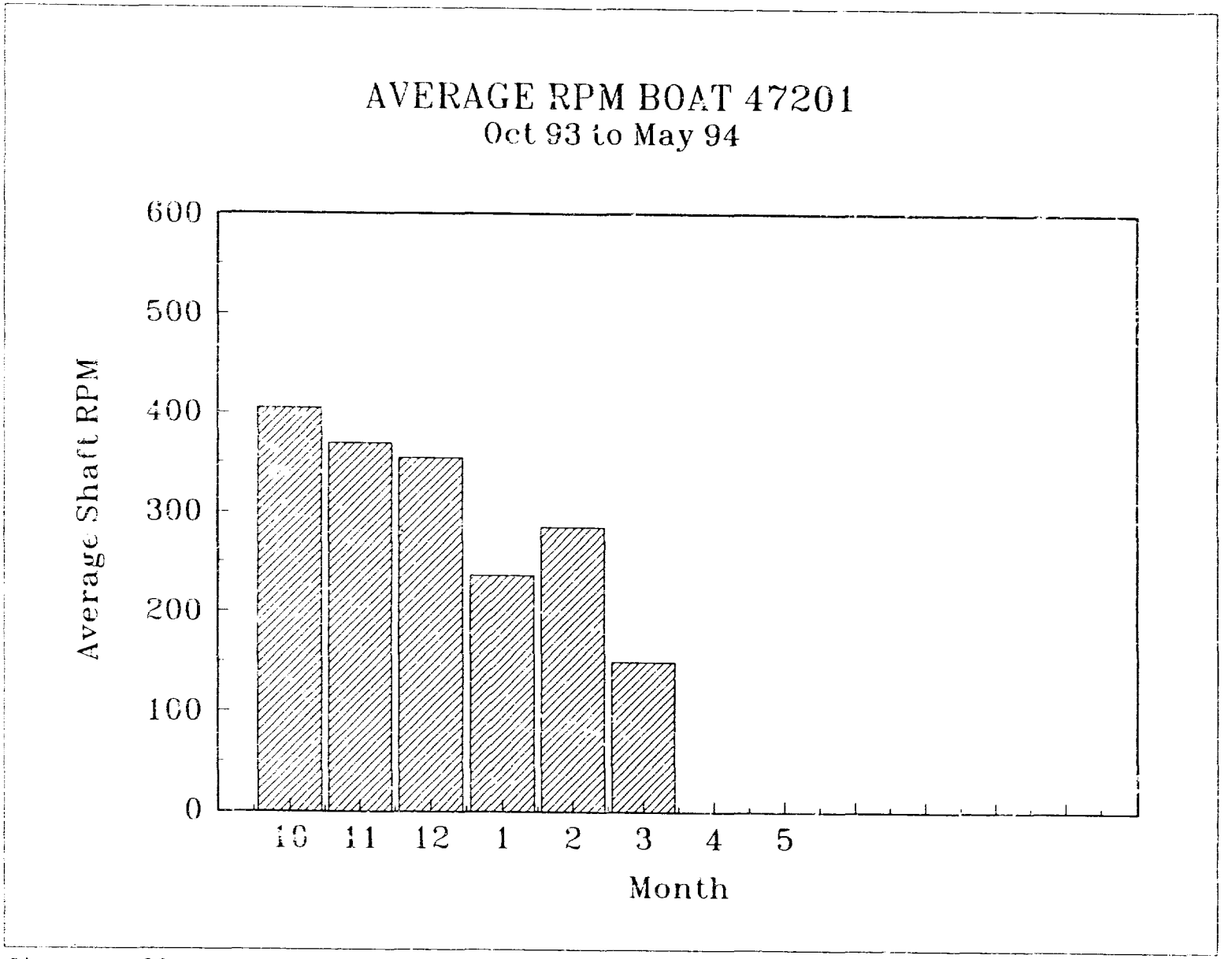


Figure A-28. 47201 Average RPM

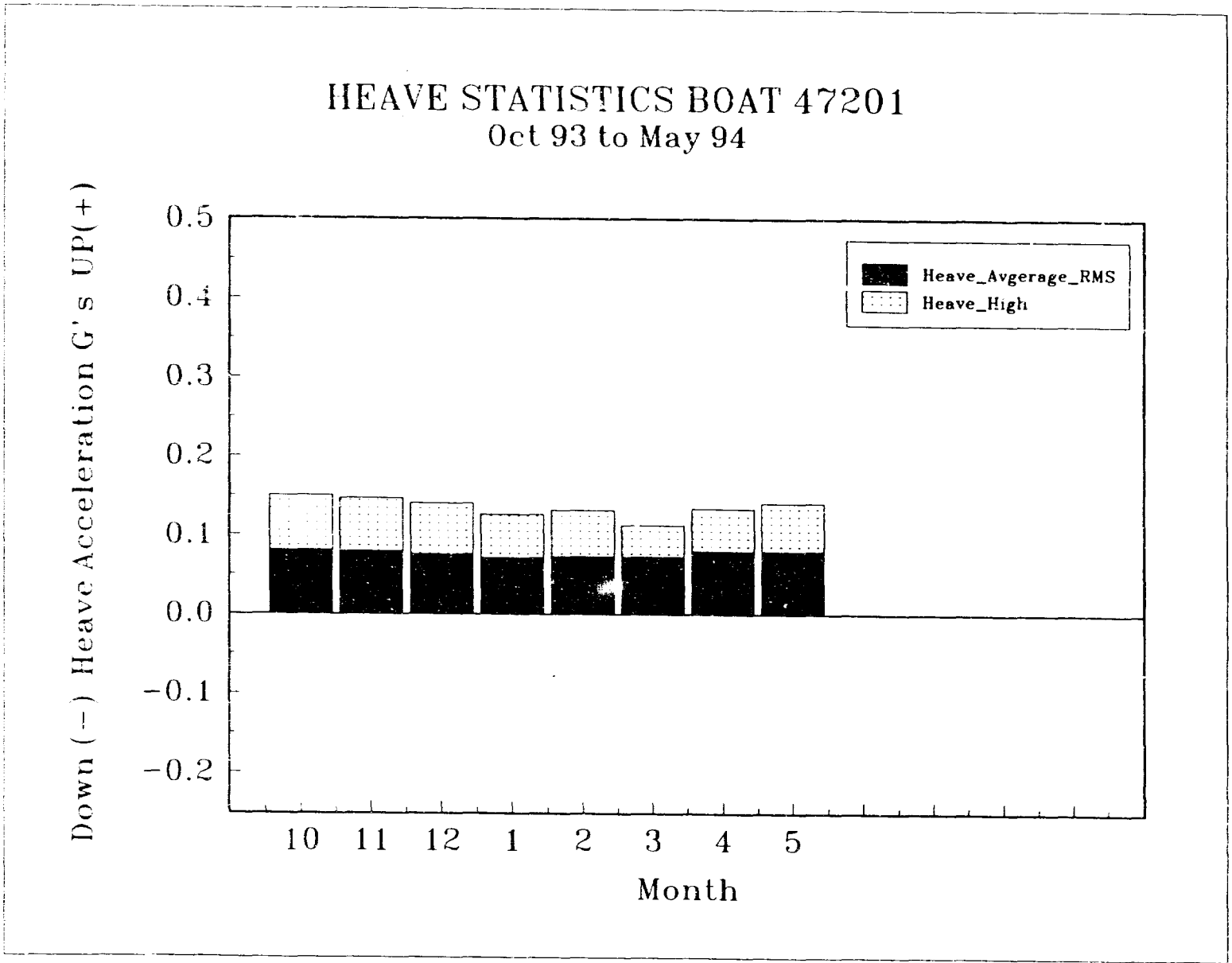


Figure A-29. 47201 Heave Statistics

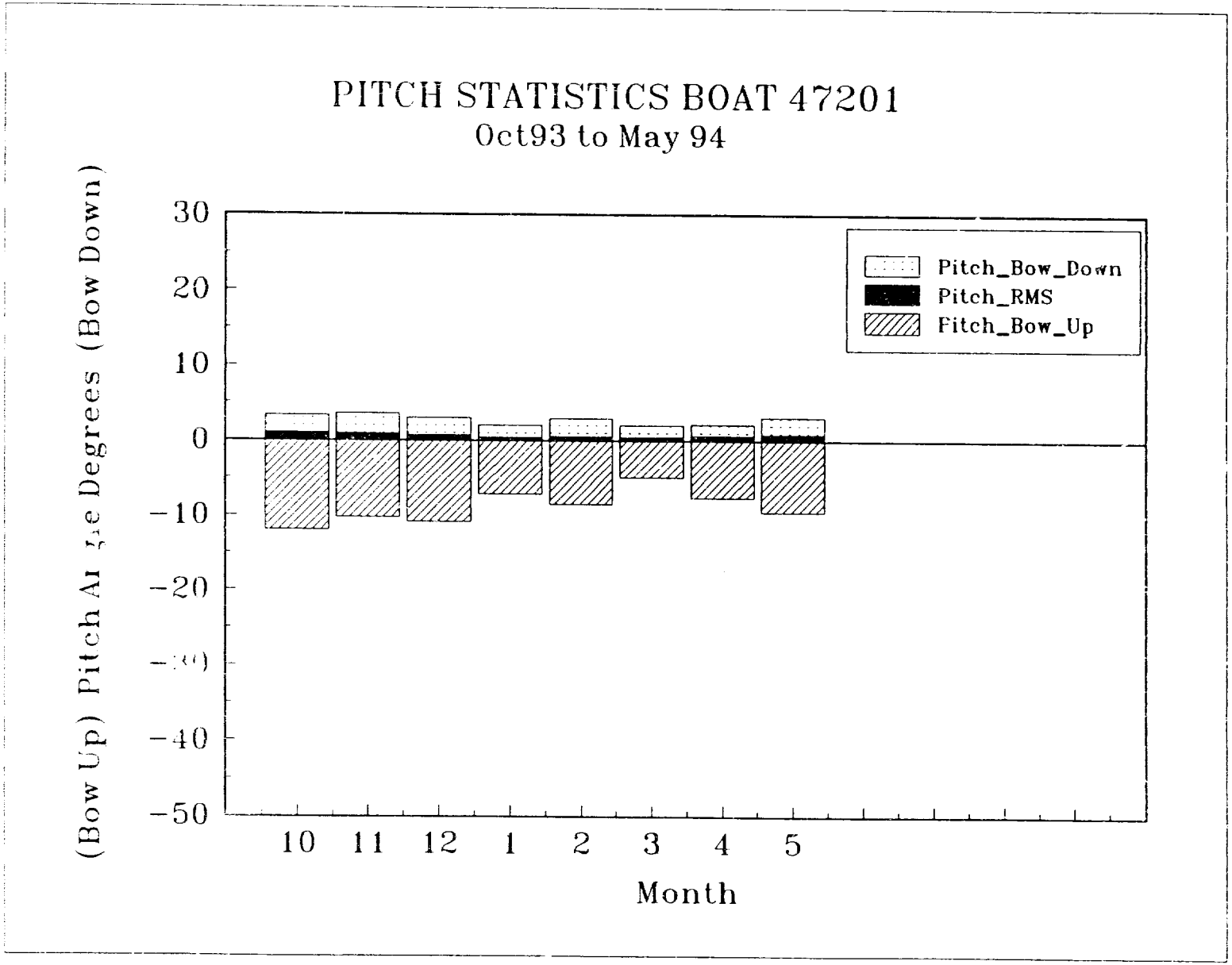


Figure A-30. 47201 Pitch Statistics

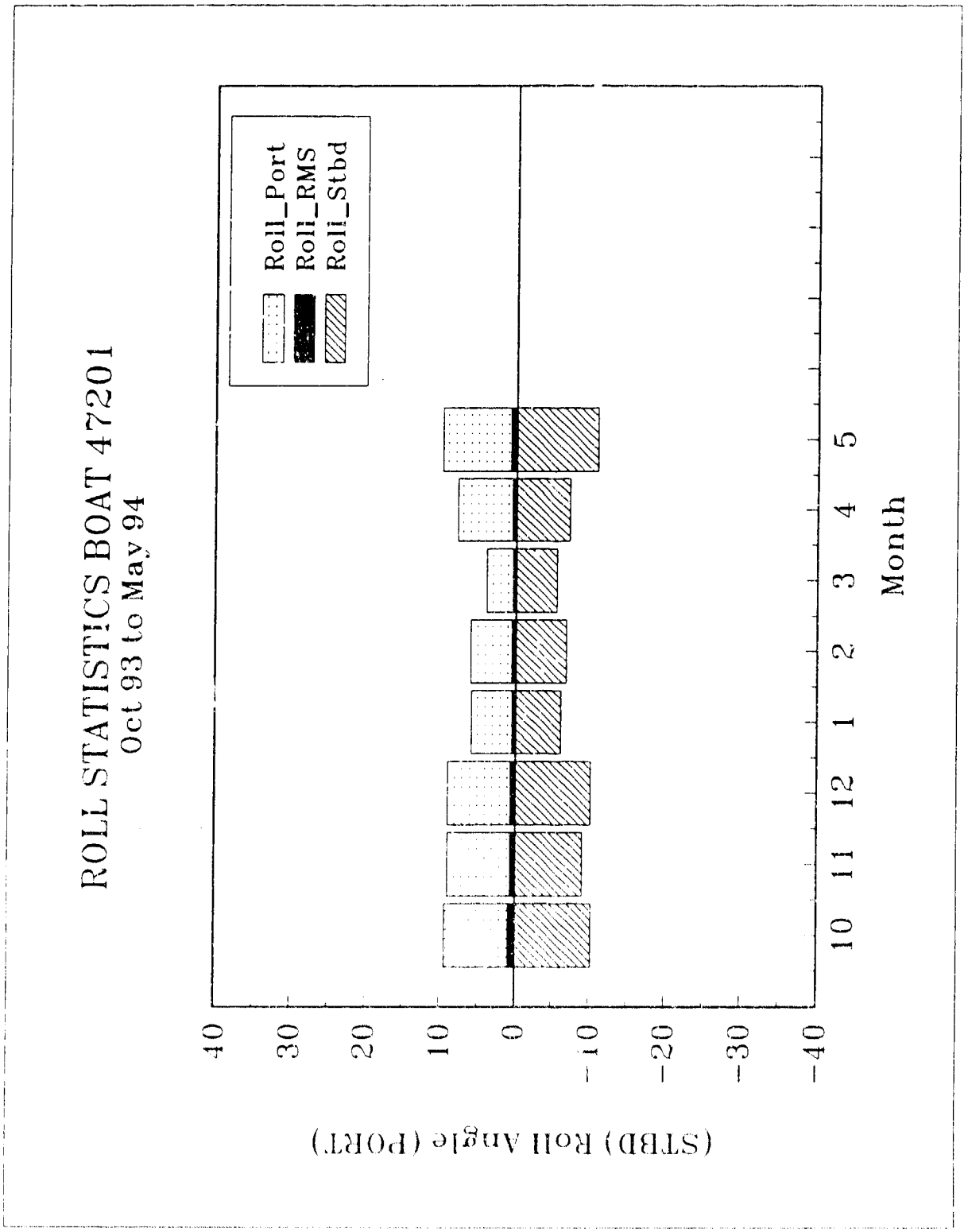


Figure A-31. 47201 Roll Statistics

APPENDIX B

47202 DATA RESULTS

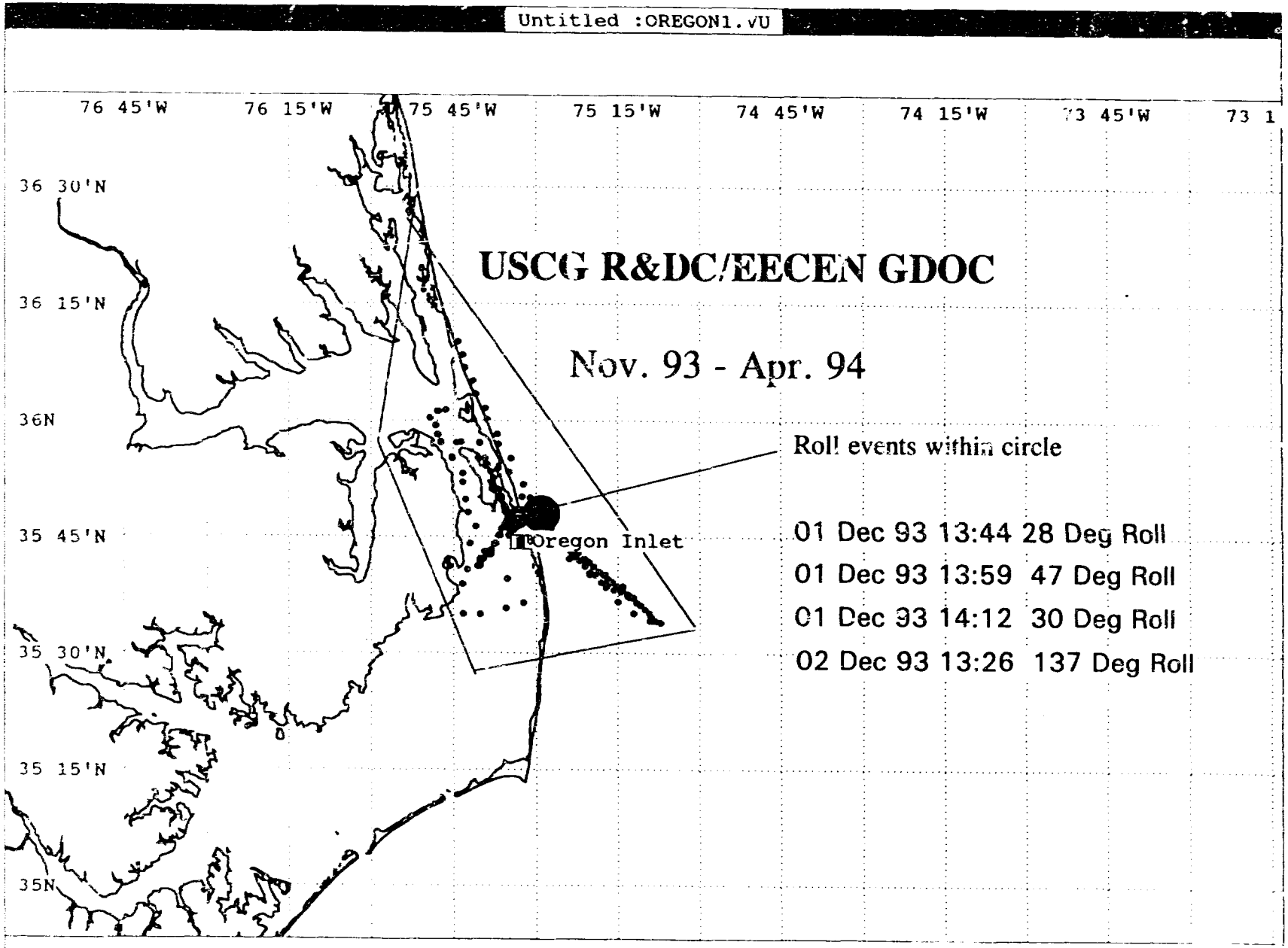


Figure B-1. Area of Recorded Operations for 47202

TABLE B-I. 47202 EVENT SUMMARY TABLE

Summary of Data Collected with the MDR

Boat: 47202
Date: 01 DEC 93
Dock Departure (Shore-tie Disconnected): 07:28
Time of Event: 13:44:19
Location: 35 deg, 47.38 min. lat.; 75 deg, 31.51 min. long.
Maximum Roll Angle Detected: APPROXIMATE 28 degrees *
Time Spent Past 90 Degrees: N.A.
Time Spent Past 45 Degrees: N.A.

* This is not a true event as defined by the 45° threshold setting on the 47202. The recording of this event was triggered by several consecutive spurious values which exceeded the threshold setting. This occurred in the region defined in the 25 second roll plot. The first 45 seconds of the beginning of the buffer were lost as evident in the time history plots for this event.

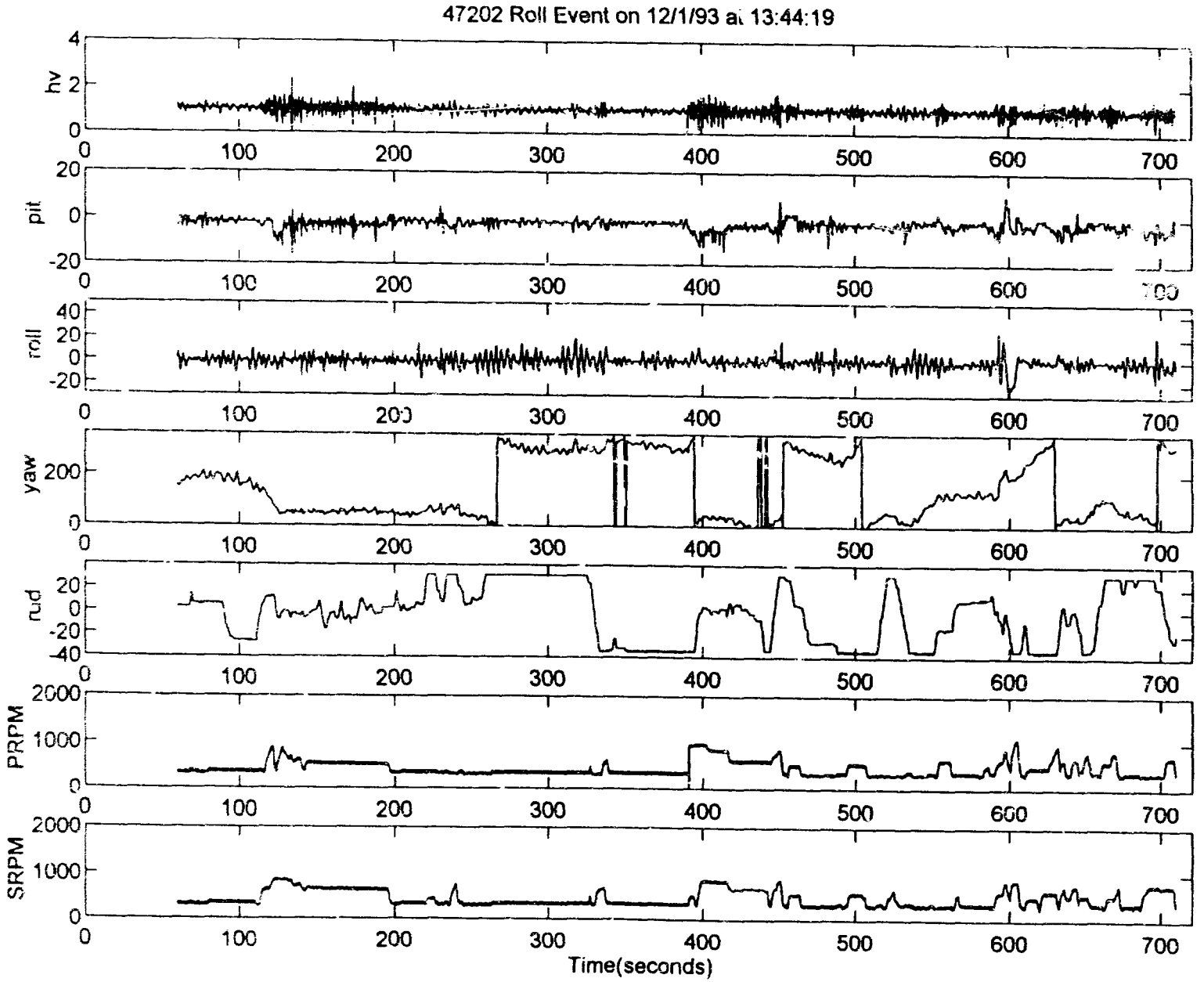


Figure B-2. 47202 Event Summary Plot (12 minutes)

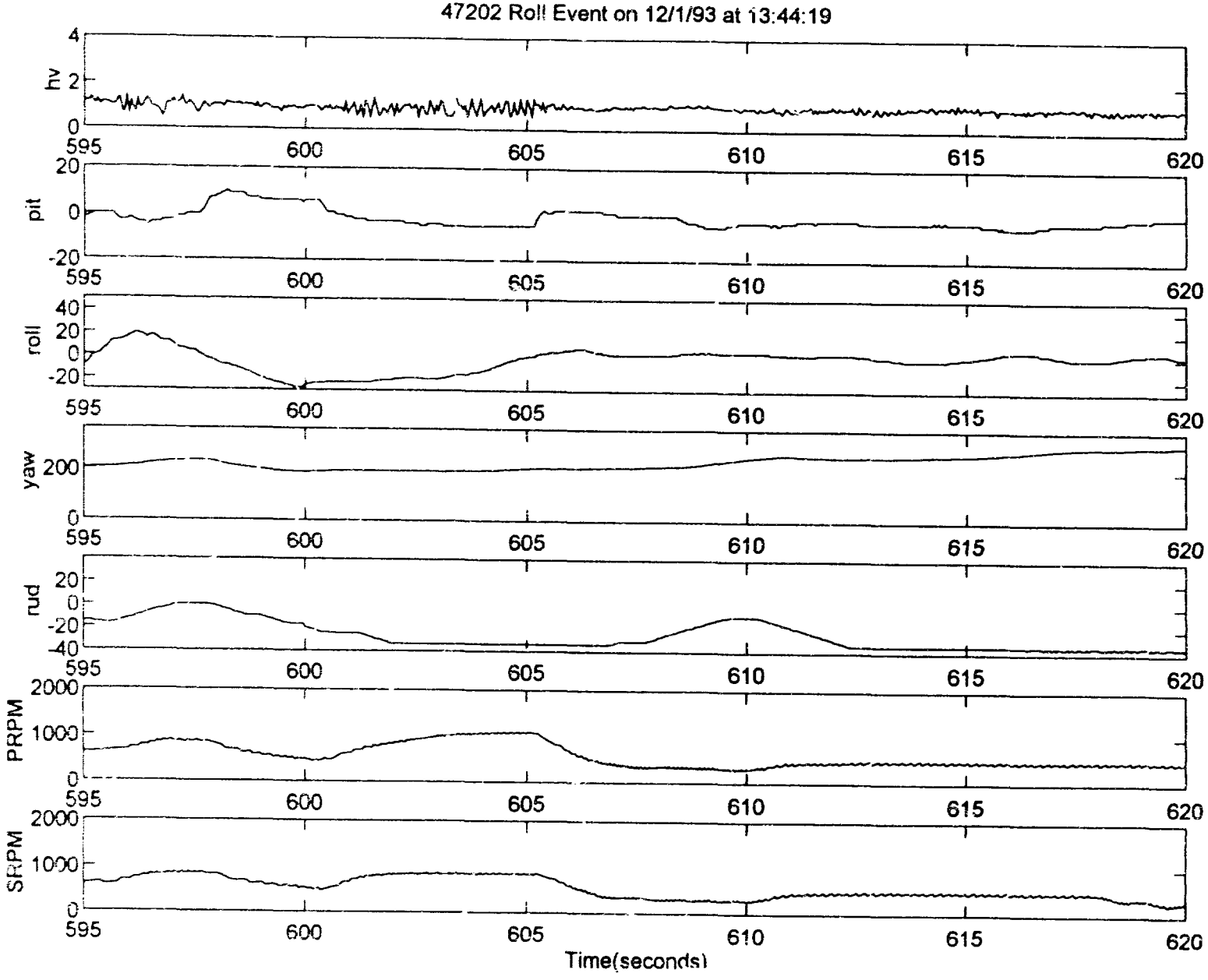


Figure B-3. 47202 Event Summary Plot (25 seconds)

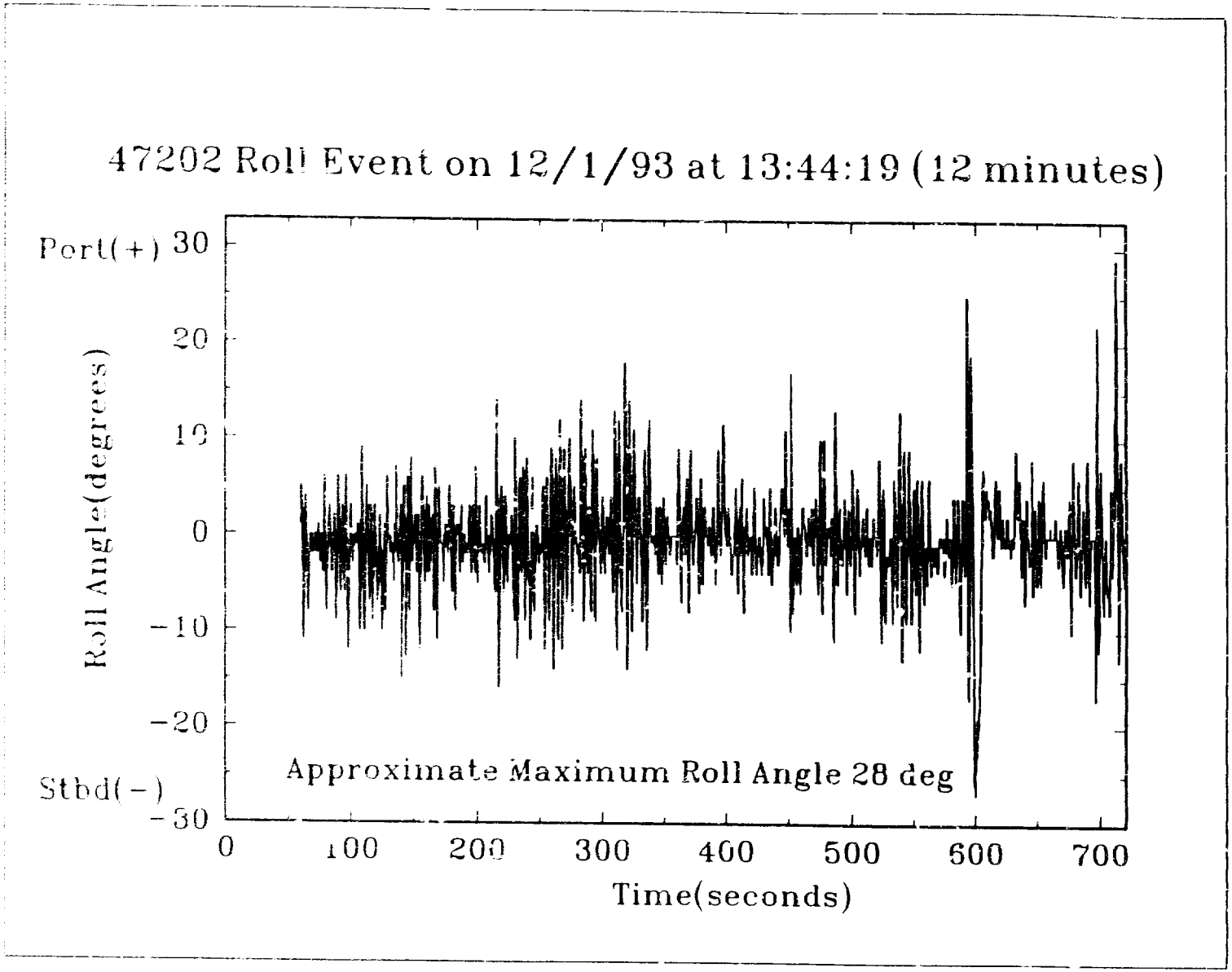


Figure B-4. 47202 Roll Data (12 minutes)

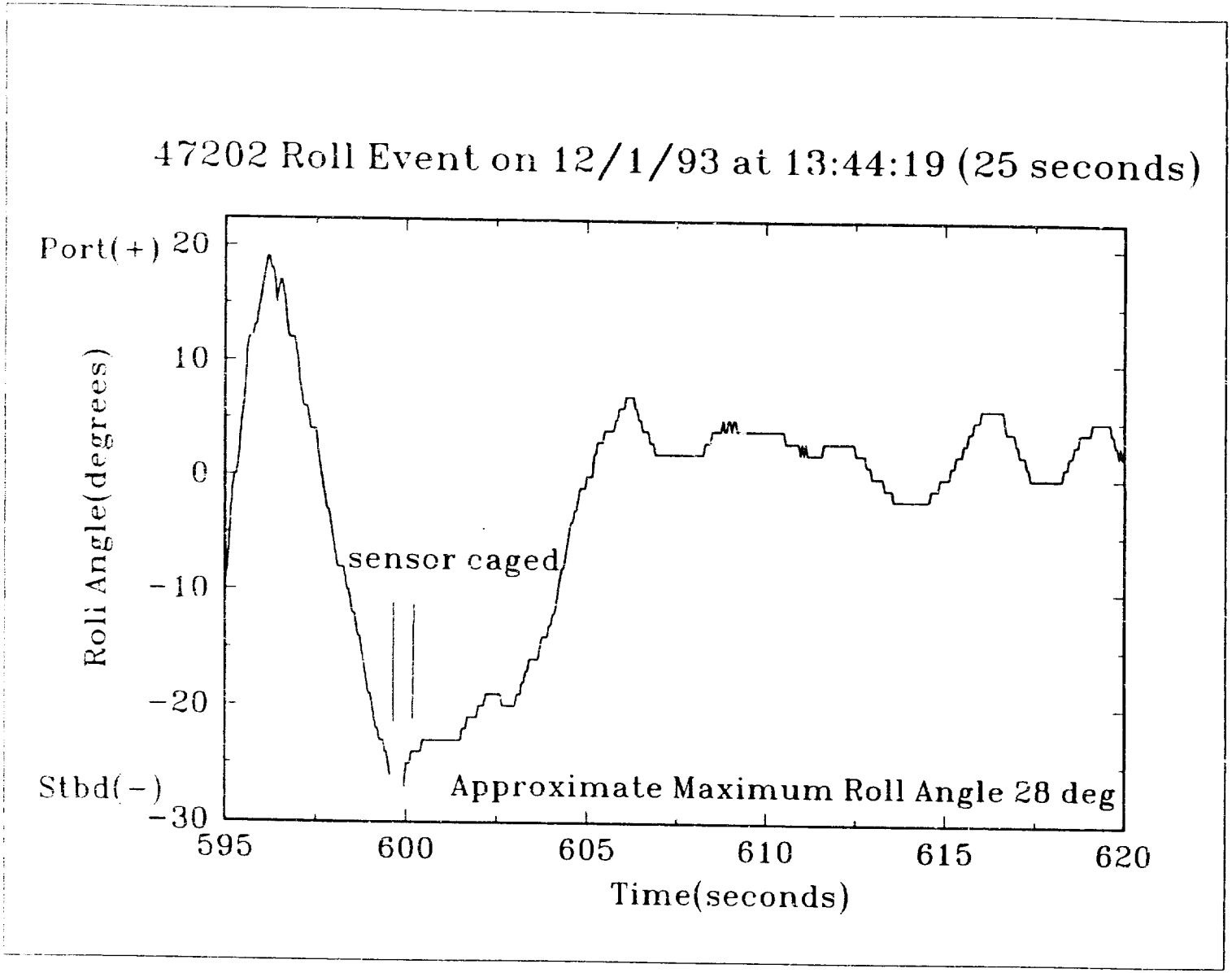


Figure B-5. 47202 Roll Data (25 seconds)

TABLE B-II. 47202 EVENT SUMMARY TABLE

Summary of Data Collected with the MDR

Boat: 47202
Date: 01 DEC 93
Dock Departure (Shore-tie Disconnected): 07:28
Time of Event: 13:59:58
Location: 35 deg, 47.30 min. lat.; 75 deg, 31.13 min. long.
Maximum Roll Angle Detected: 47 degrees to Port
Time Spent Past 90 Degrees: N.A.
Time Spent Past 45 Degrees: 0.6 seconds

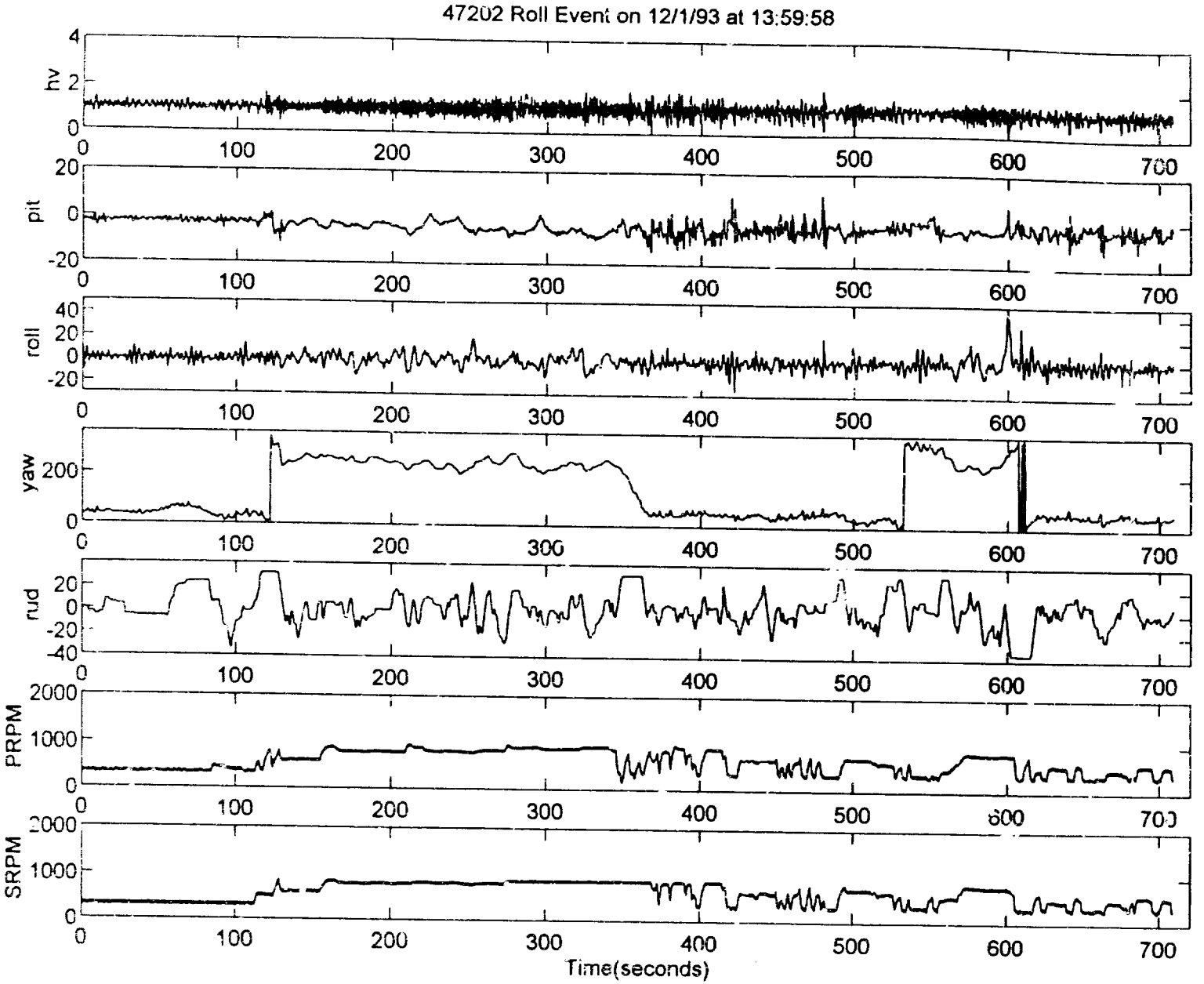


Figure B-6. 47202 Event Summary Plot (12 minutes)

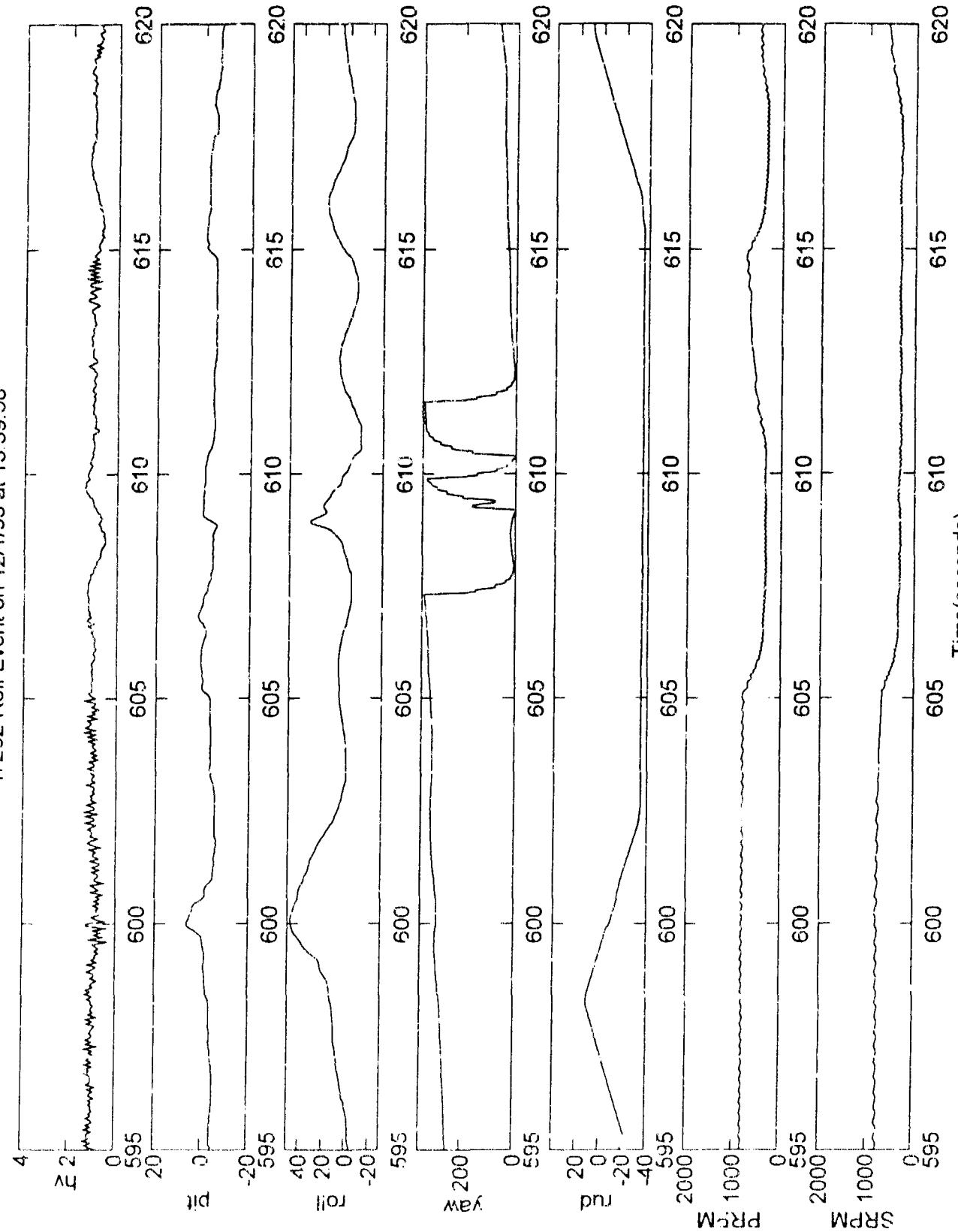


Figure B-7. 47202 Event Summary Plot (25 seconds)

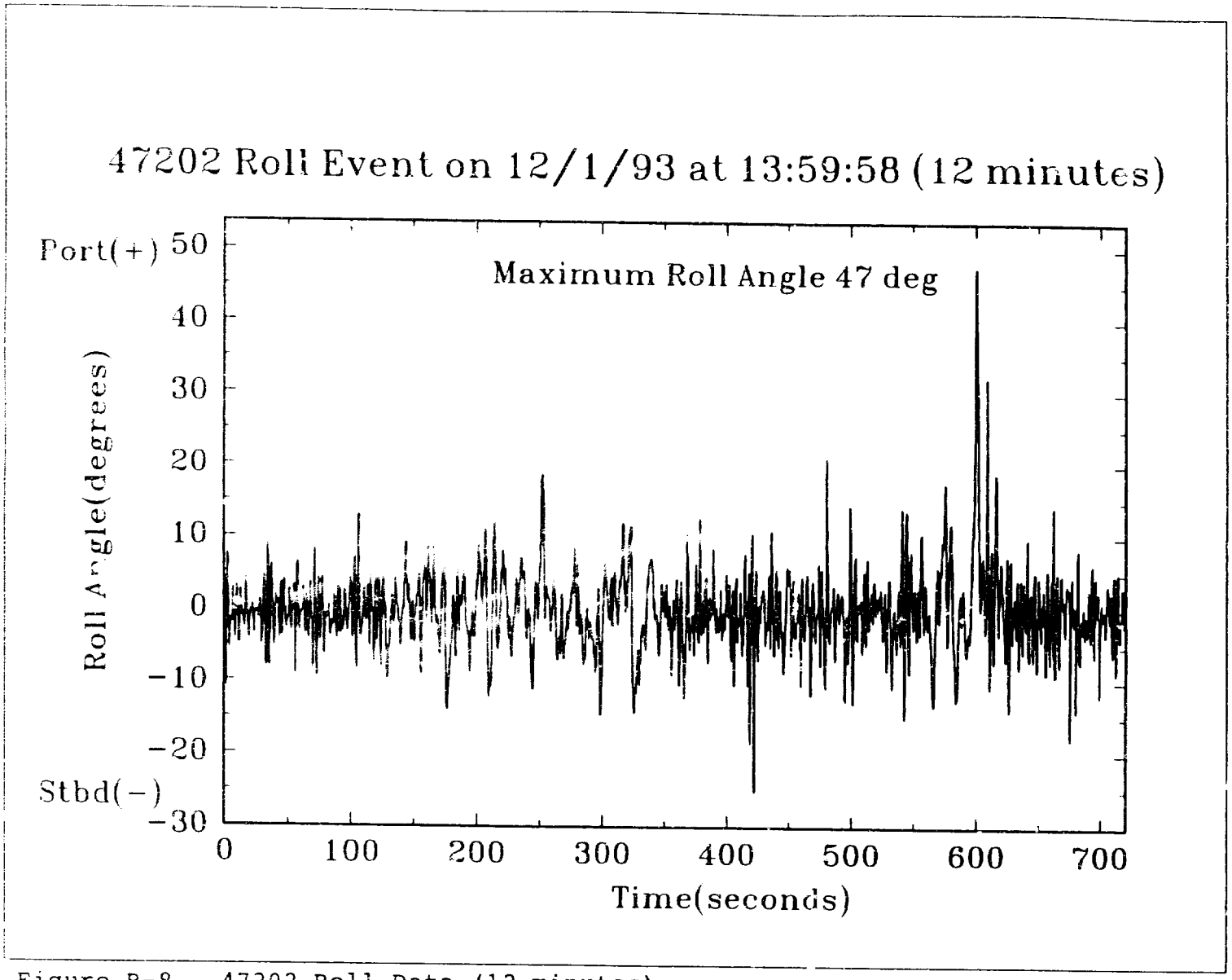


Figure B-8. 47202 Roll Data (12 minutes)

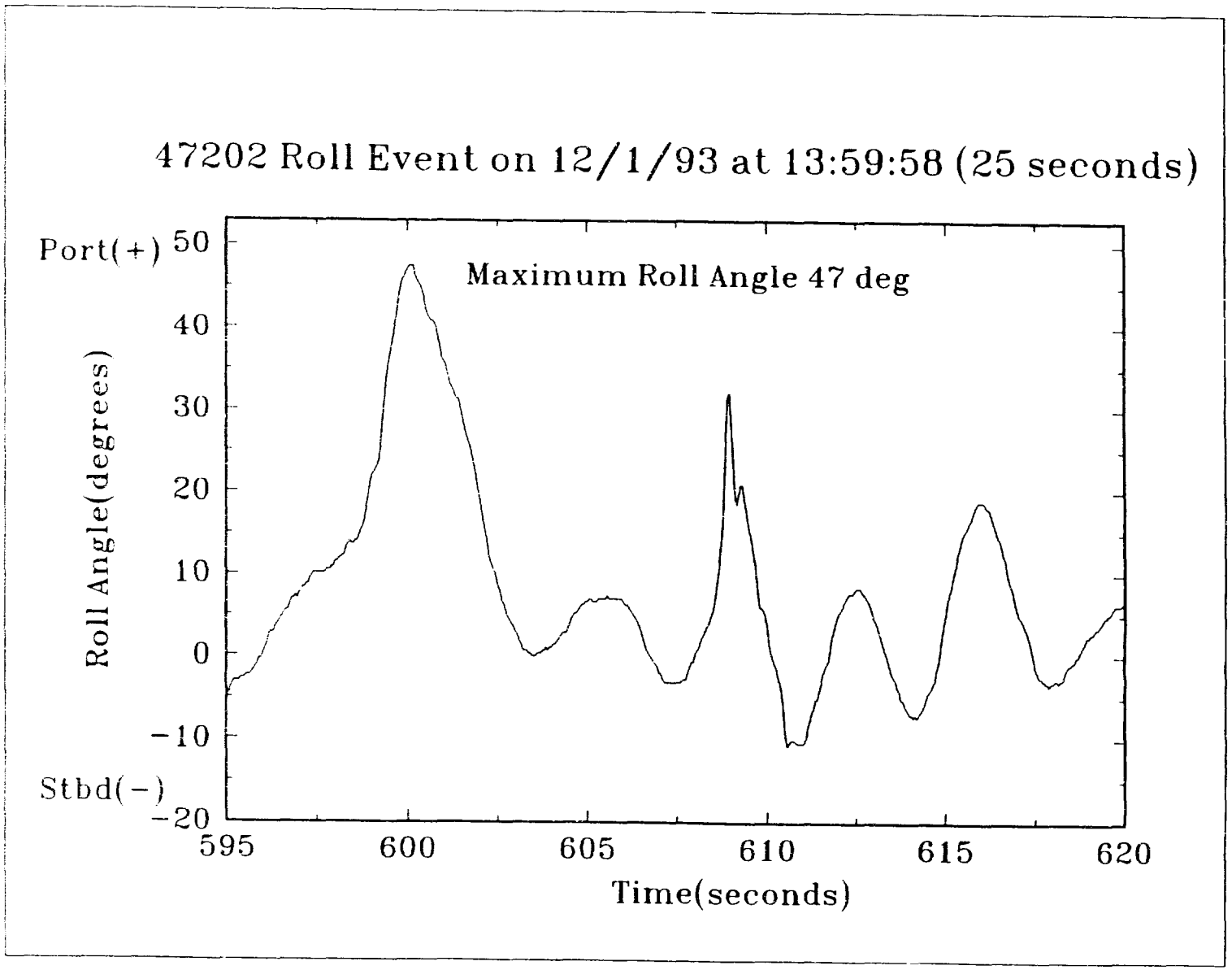


Figure B-9. 47202 Roll Data (25 seconds)

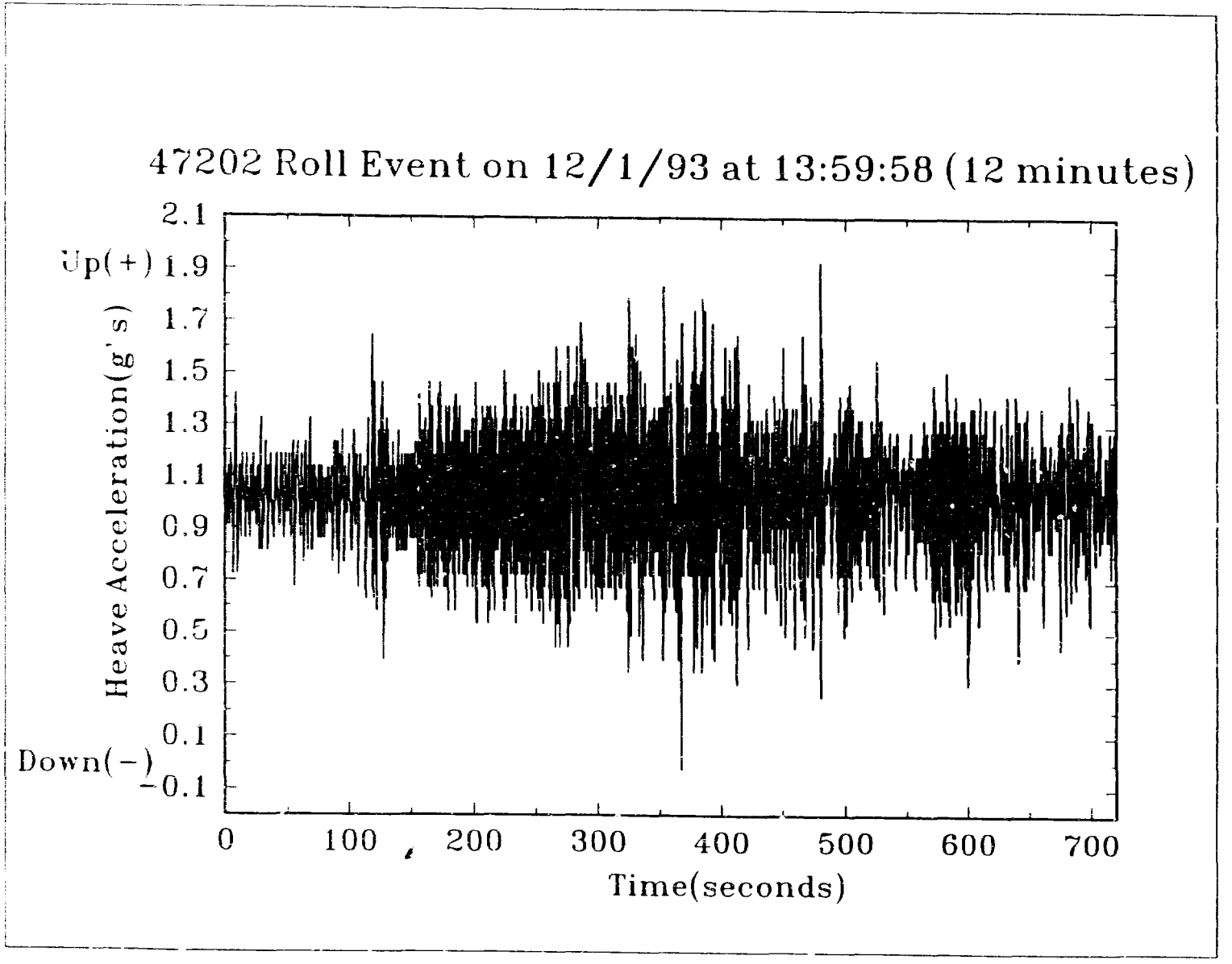


Figure B-10. 47202 Heave Data (12 minutes)

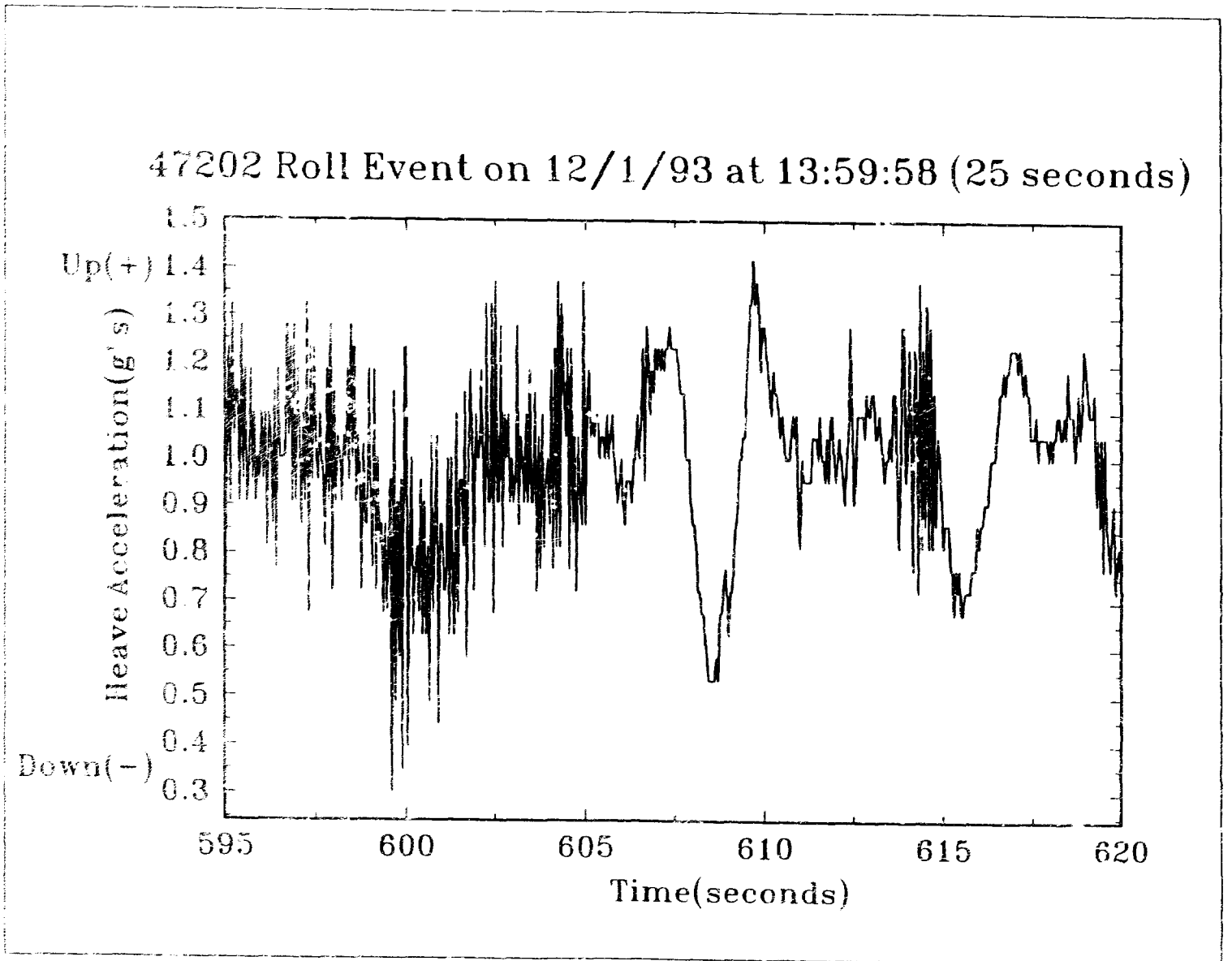


Figure B-11. 47202 Heave Data (25 seconds)

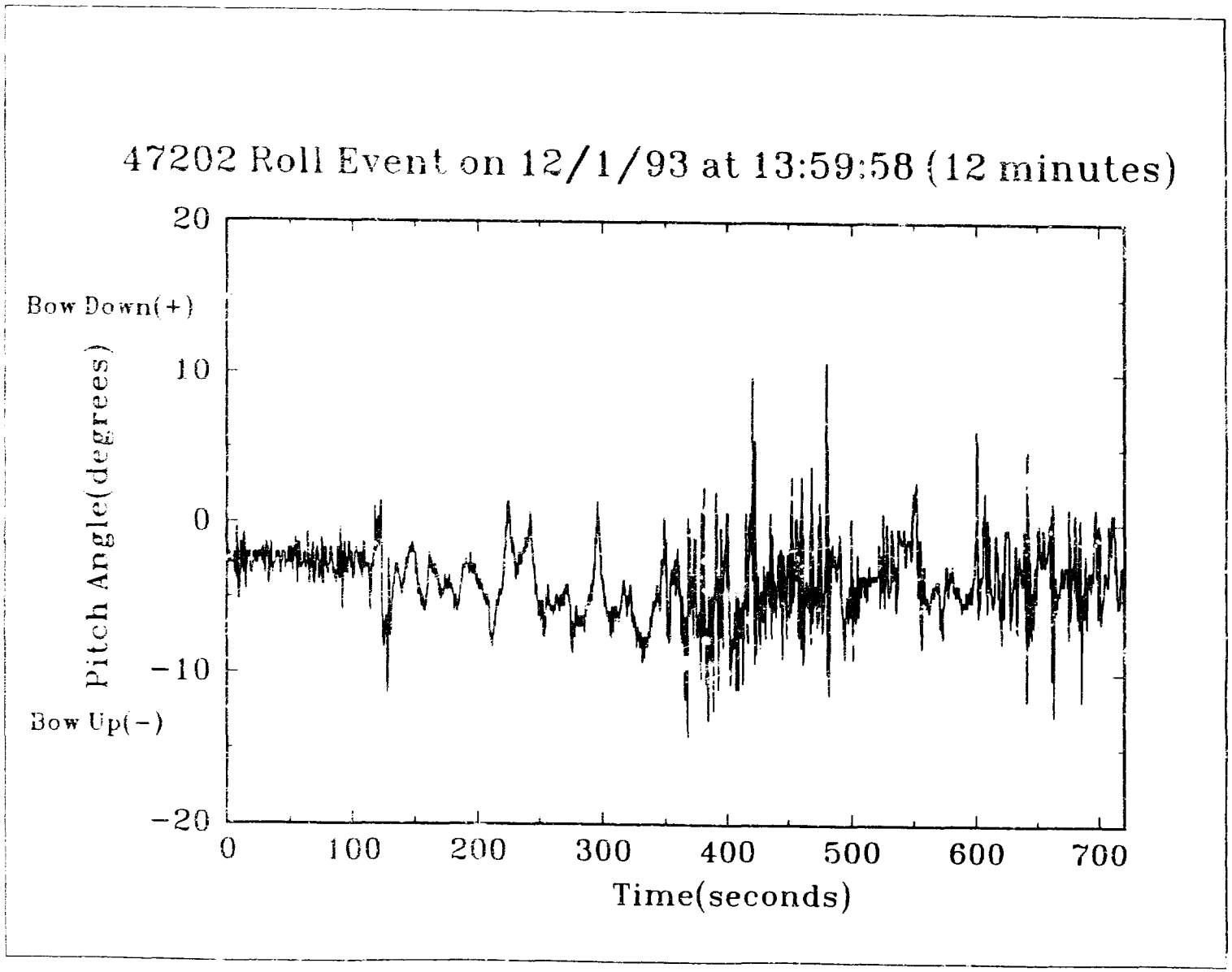


Figure B-12. 17202 Pitch Data (12 minutes)

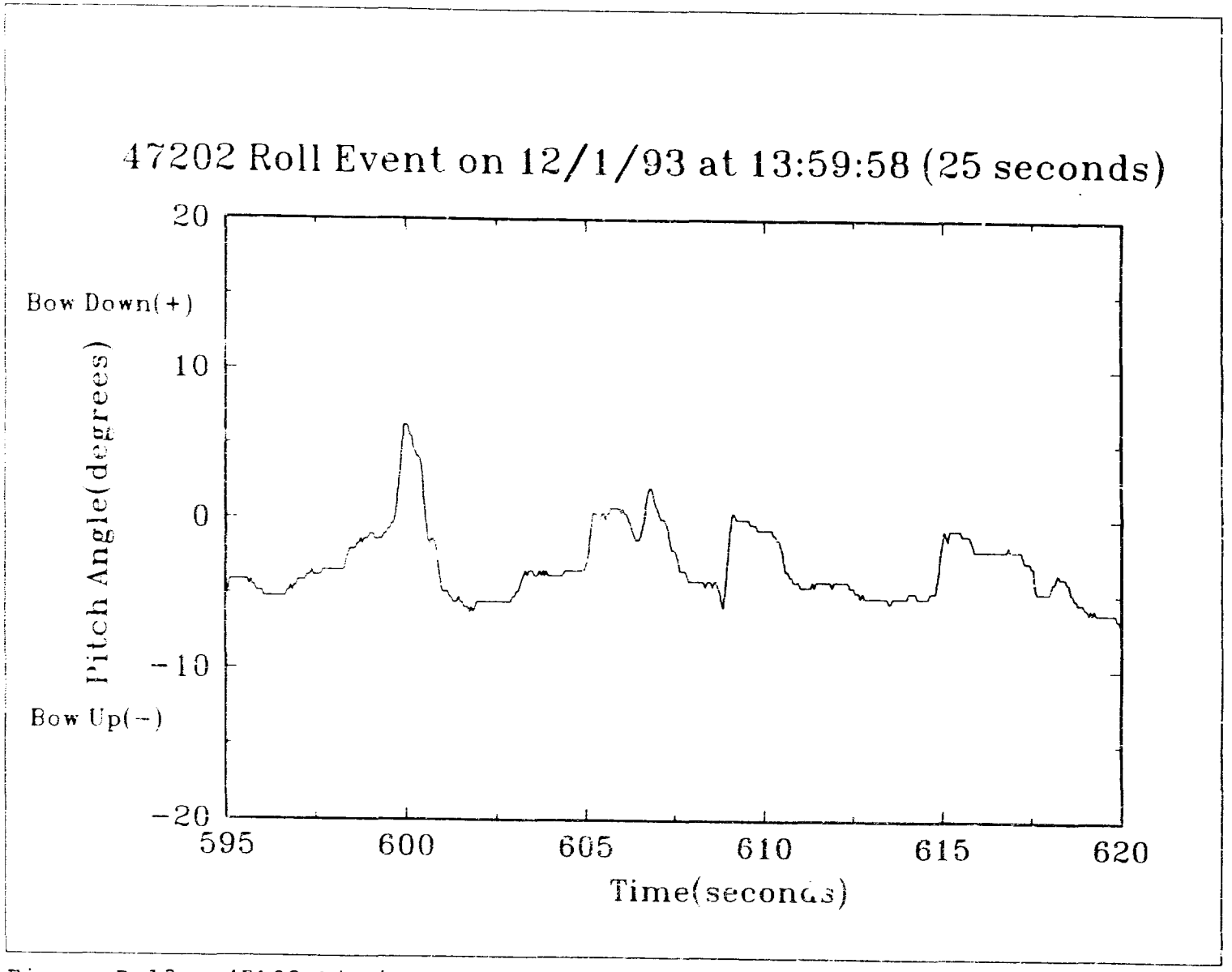


Figure B-13. 47202 Pitch Data (25 seconds)

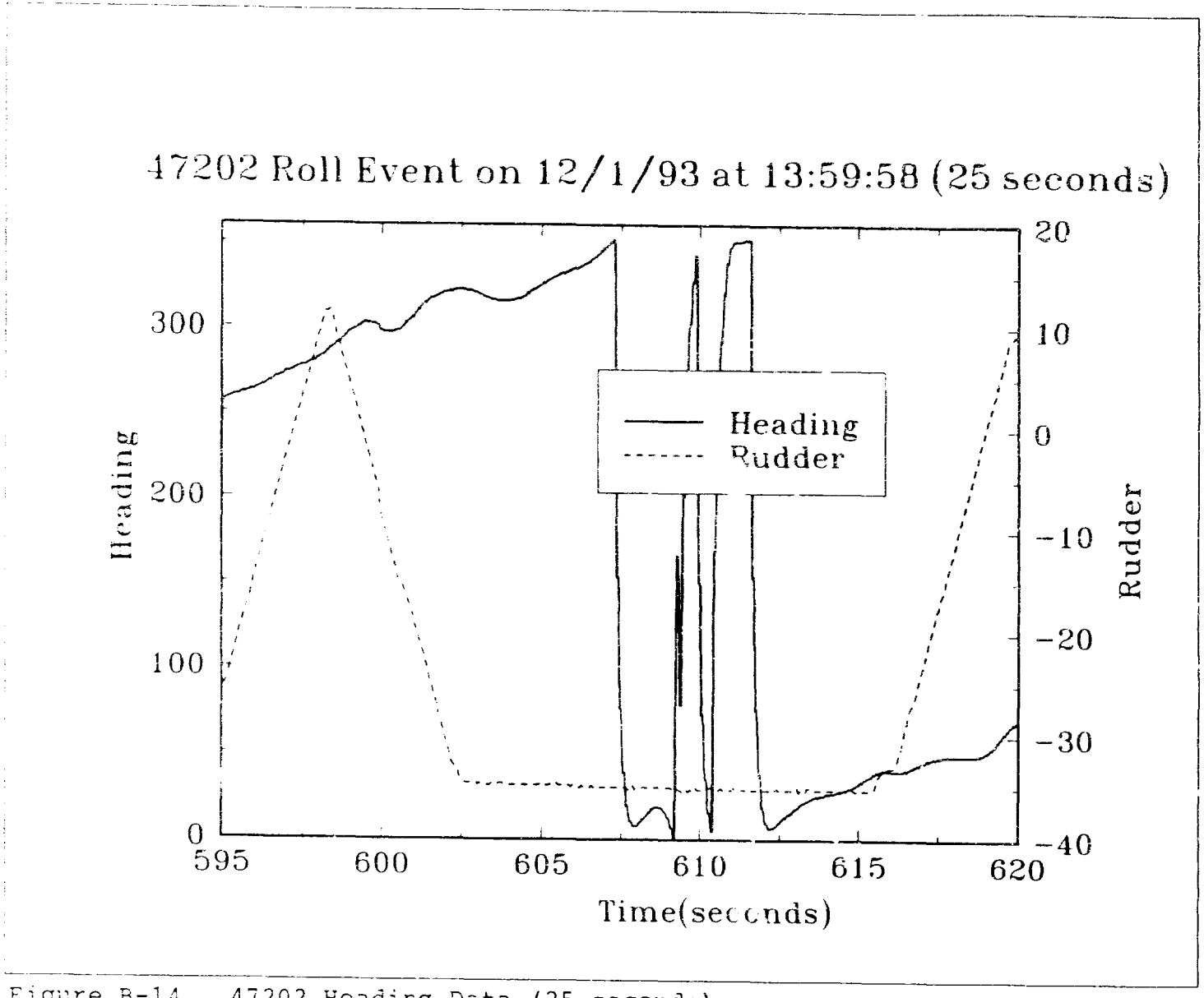


Figure B-14. 47202 Heading Data (25 seconds)

TABLE B-III. 47202 EVENT SUMMARY TABLE

Summary of Data Collected with the MDR

Boat: 47202
Date: 01 DEC 93
Dock Departure (Shore-tie Disconnected): 07:28
Time of Event: 14:12:12
Location: 35 deg, 47.30 min. lat.; 75 deg, 31.13 min. long.
Maximum Roll Angle Detected: 30 degrees*
Time Spent Past 90 Degrees: N.A.
Time Spent Past 45 Degrees: N.A.

* This is not a true event as defined by the 45° roll threshold setting on the 47202. The recording of this event was triggered by several consecutive spurious values which exceeded the threshold setting. Only the roll data is plotted to demonstrate that this was a 30 degree roll.

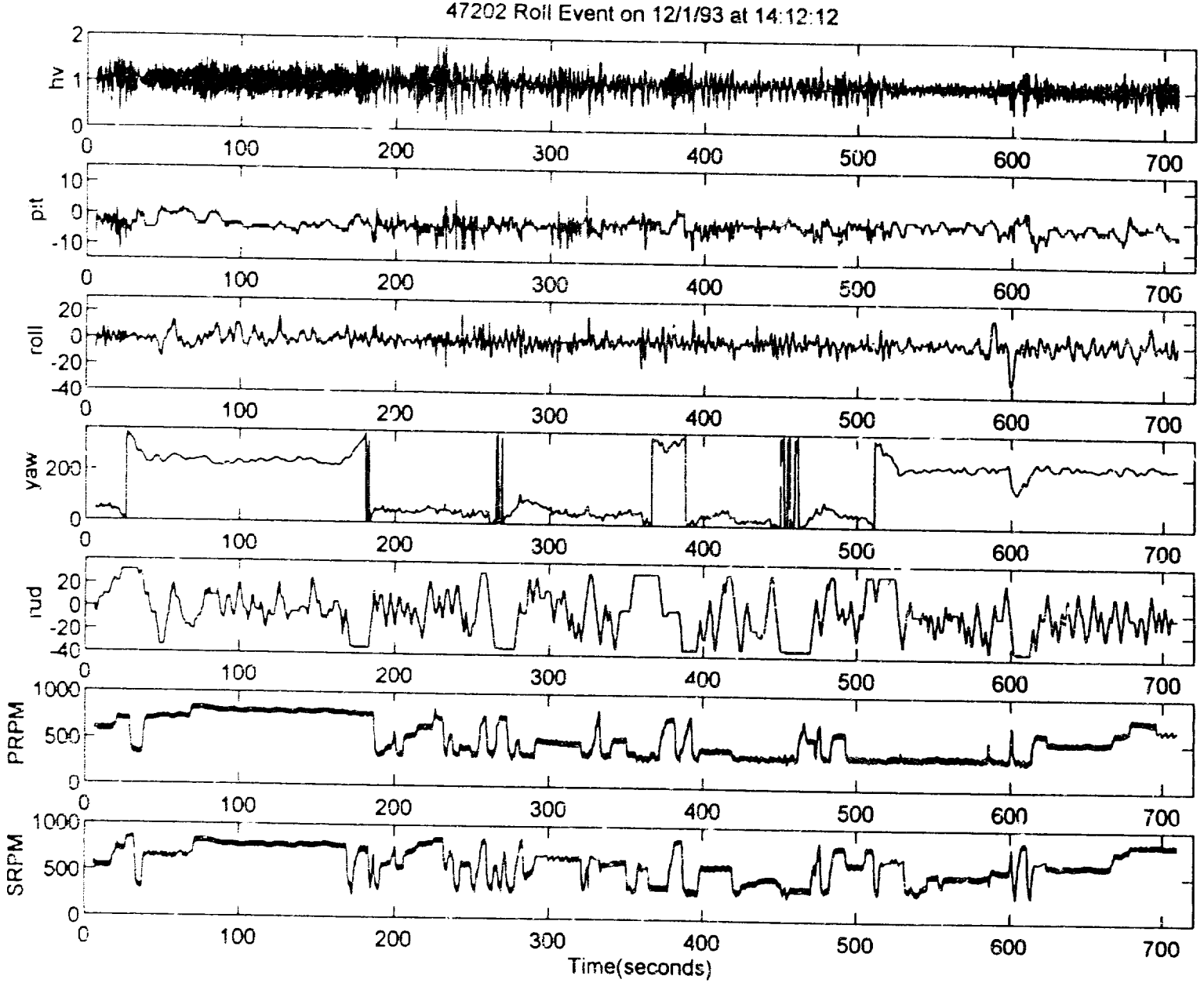


Figure B-15. 47202 Event Summary Plot (12 minutes)

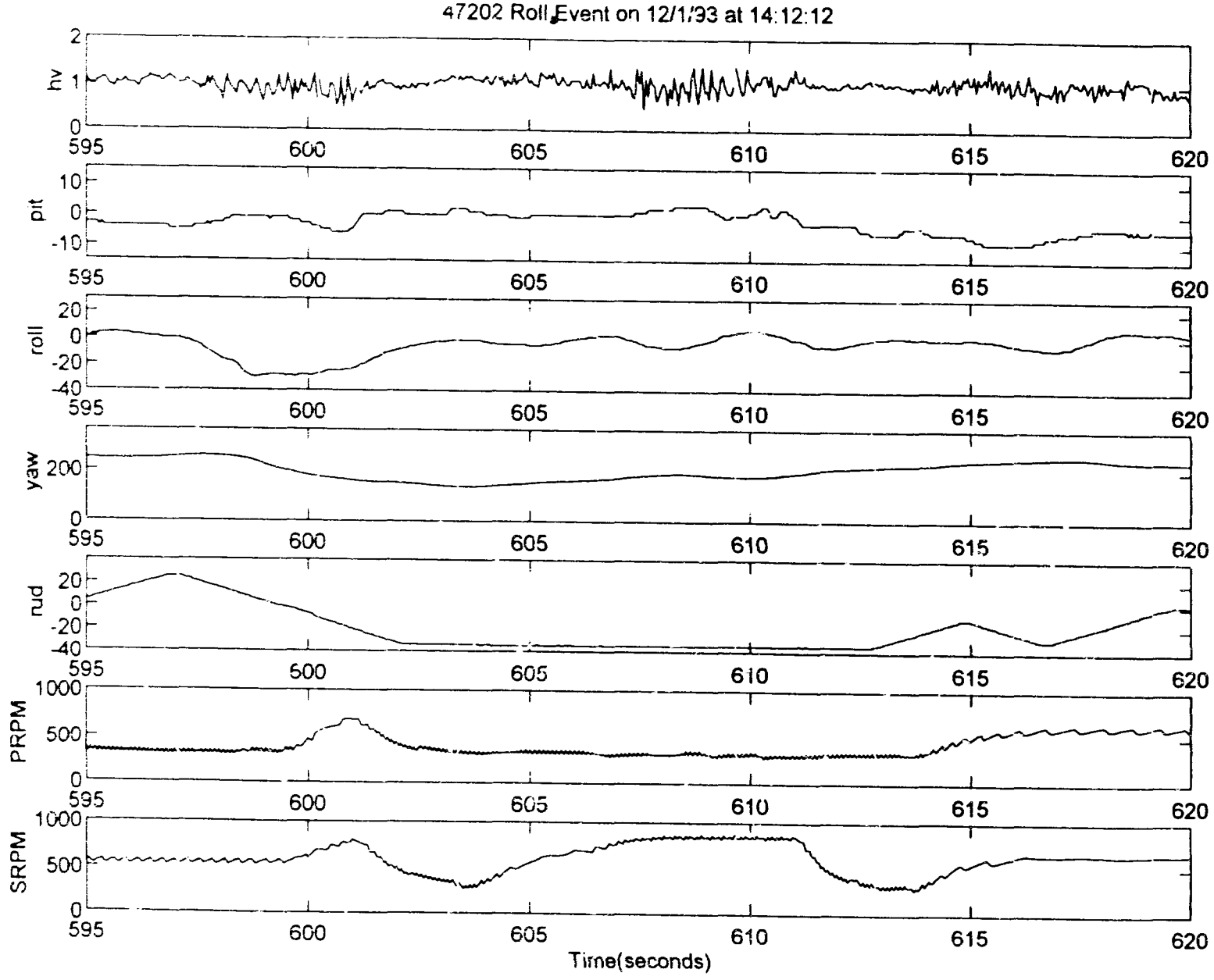


Figure B-16. 47202 Event Summary Plot (25 seconds)

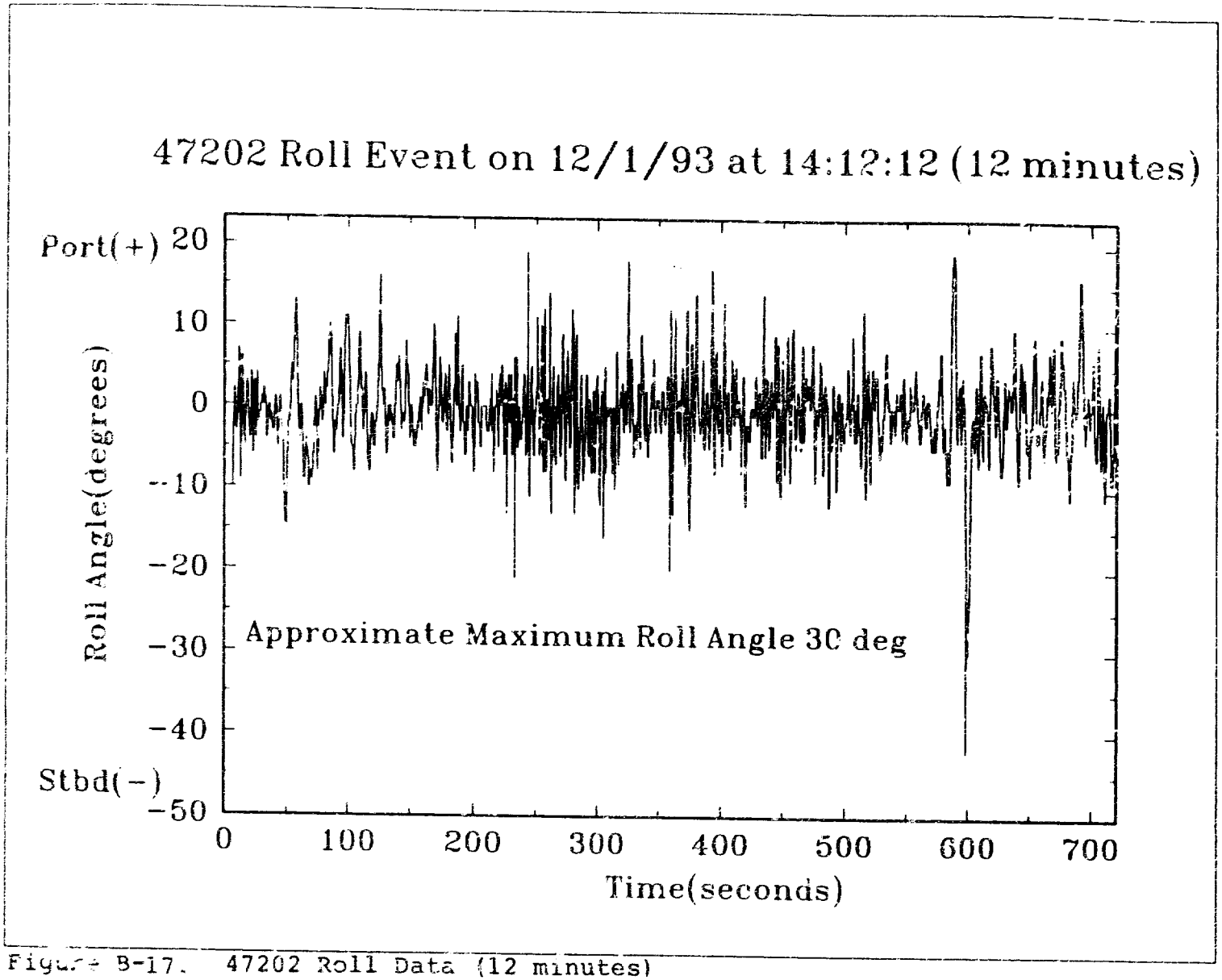


Figure B-17. 47202 Roll Data (12 minutes)

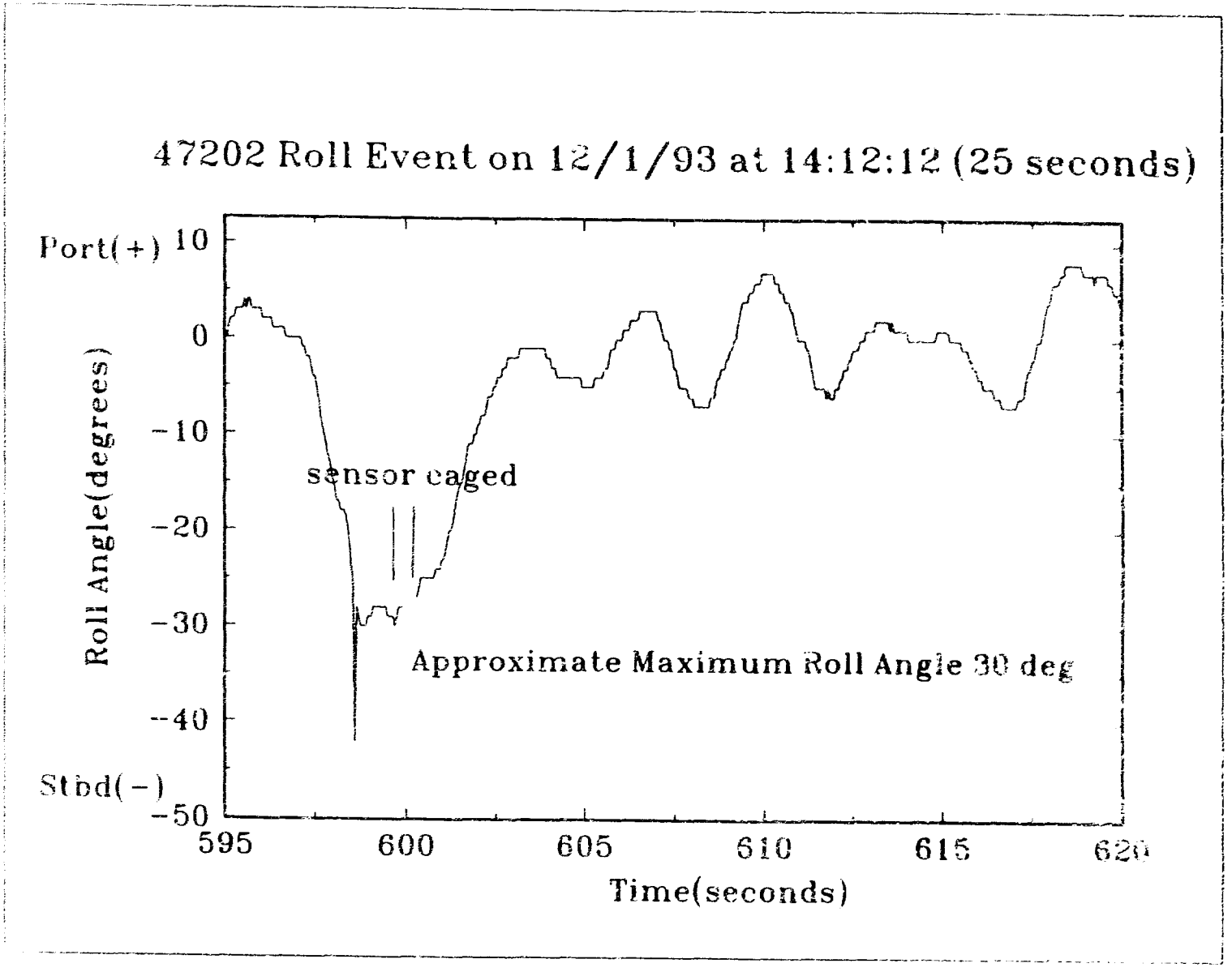


Figure B-18. 47202 Roll Data (25 seconds)

TABLE B-IV. 47202 EVENT SUMMARY TABLE

Summary of Data Collected with the MDR

Boat: 47202
Date: 02 DEC 93
Dock Departure (Shore-tie Disconnected): 12:34
Time of Event: 13:26
Location: 35 deg, 46.58 min. lat.; 75 deg, 32.16 min. long.
Maximum Roll Angle Detected: 137 degrees to Port
Time Spent Past 90 Degrees: 4.25 seconds
Time Spent Past 45 Degrees: 6.45 seconds
Stbd Engine RPM:
- Before Event - decreasing from 1700 to 750 RPM
- During Event - 750 RPM
- After Event - increasing from 750 to 1700 RPM

Port Engine RPM:
- Before Event - decreasing from 1700 to 750 RPM
- During Event - 750 RPM
- After Event - decreasing to 300 RPM

Rudder Angle:
- Before Event - 23 degrees starboard
- During Event - 2 degrees starboard
- After Event - 31 degrees port

Heading:
- Before Event - 320 degrees
- After Event - 320 degrees

Pitch: Bow down

Note: A more detailed analysis and description of this event can be found in Reference [5].

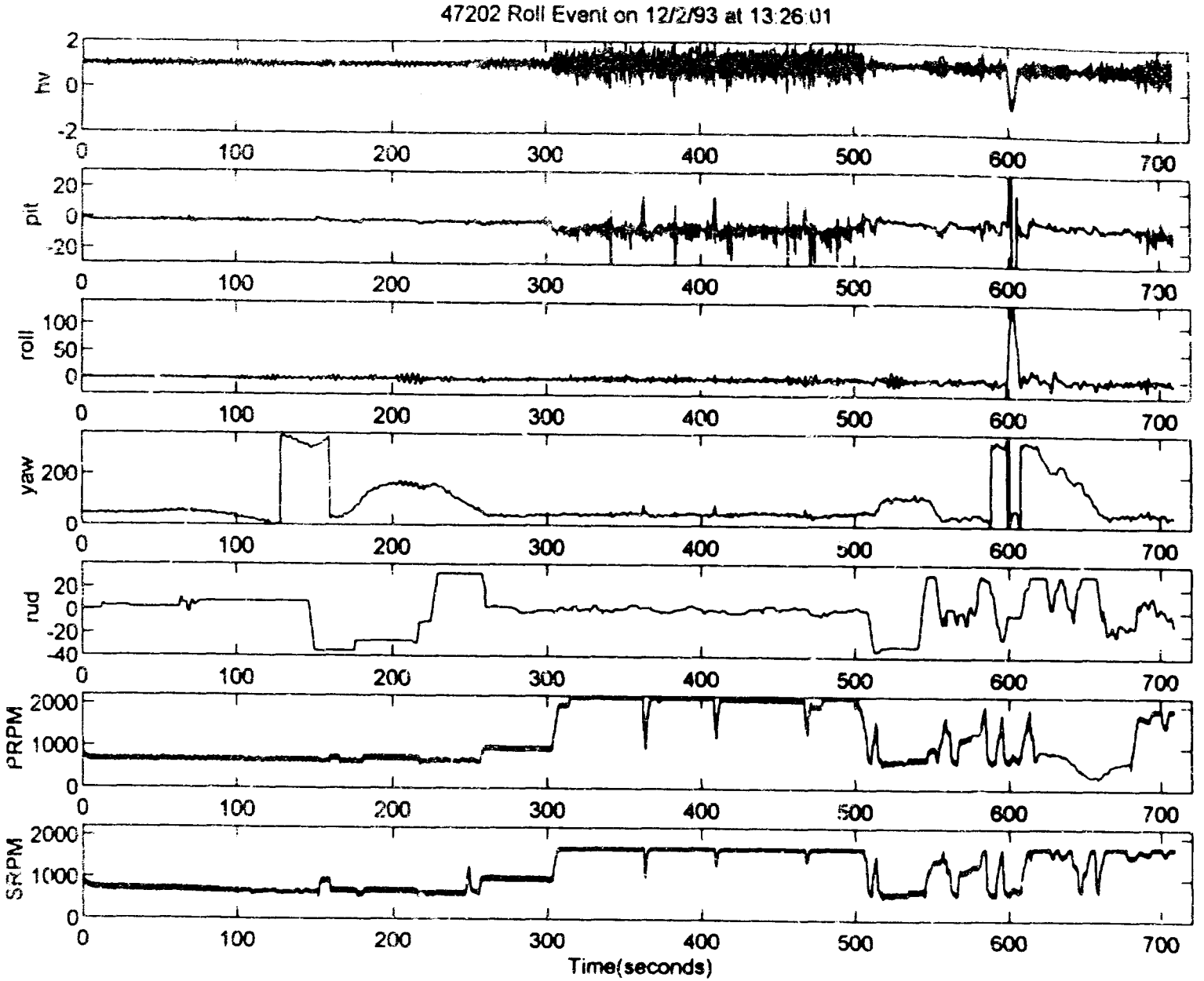


Figure B-19. 47202 Event Summary Plot (12 minutes)

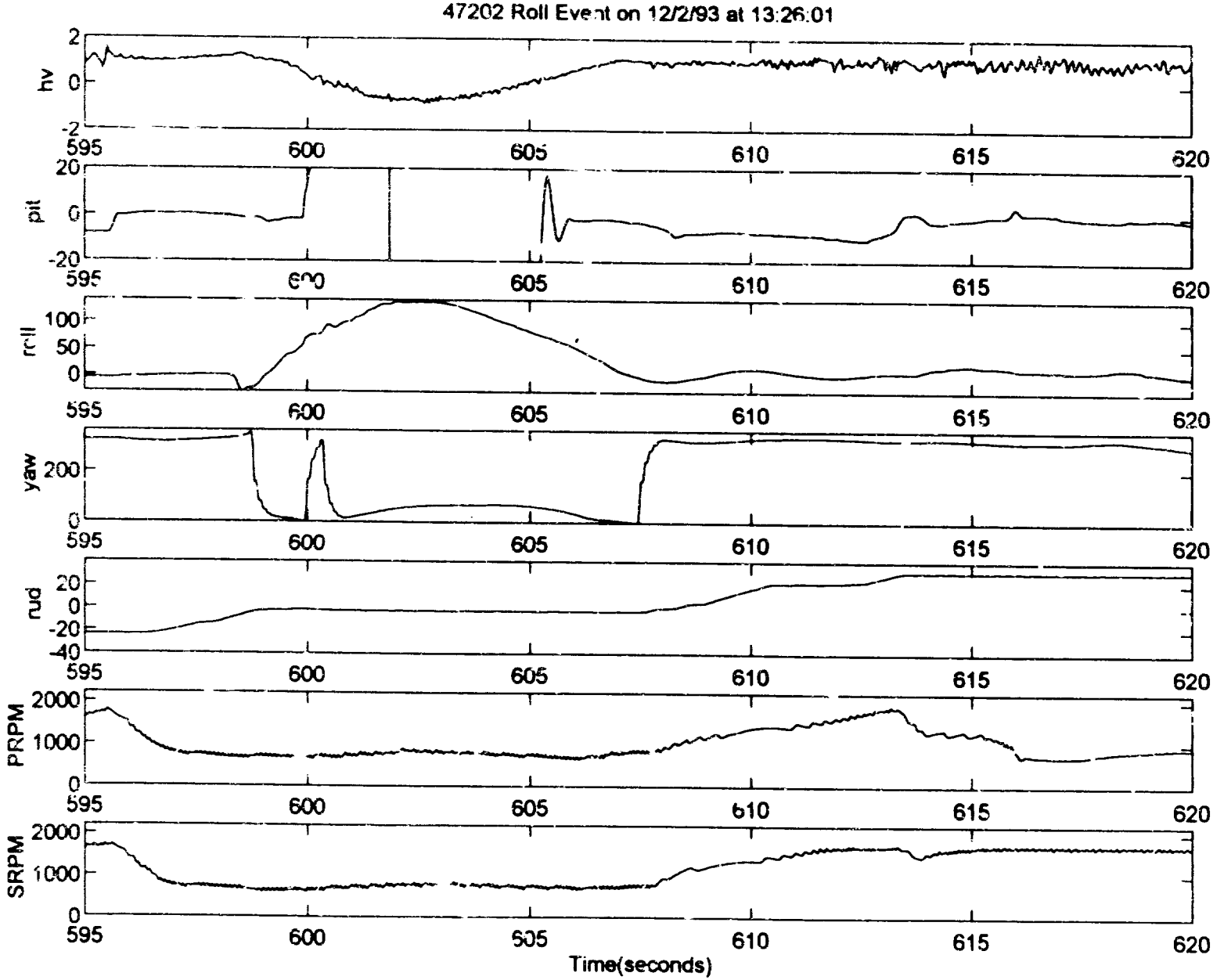


Figure B-20. 47202 Event Summary Plot (25 seconds)

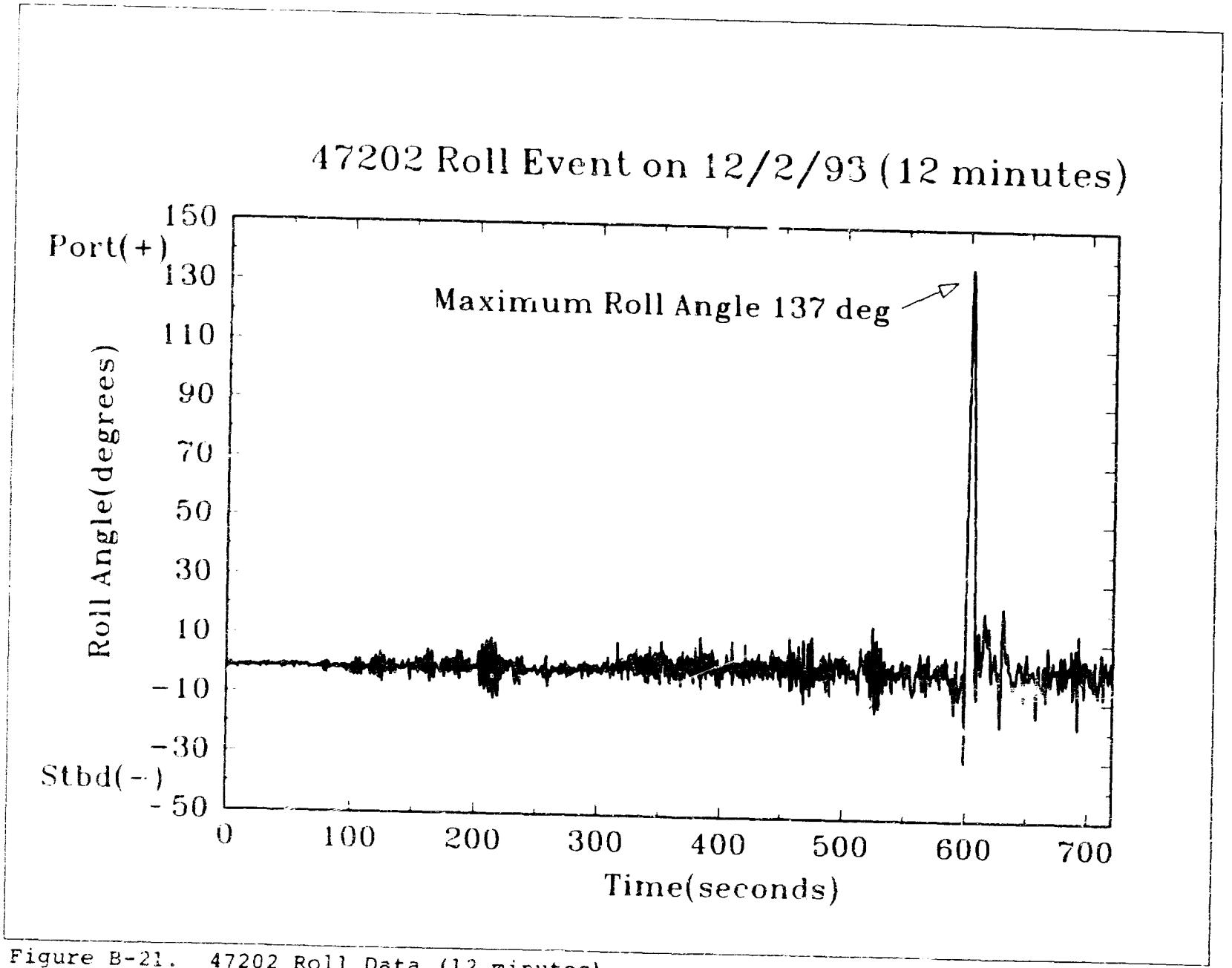


Figure B-21. 47202 Roll Data (12 minutes)

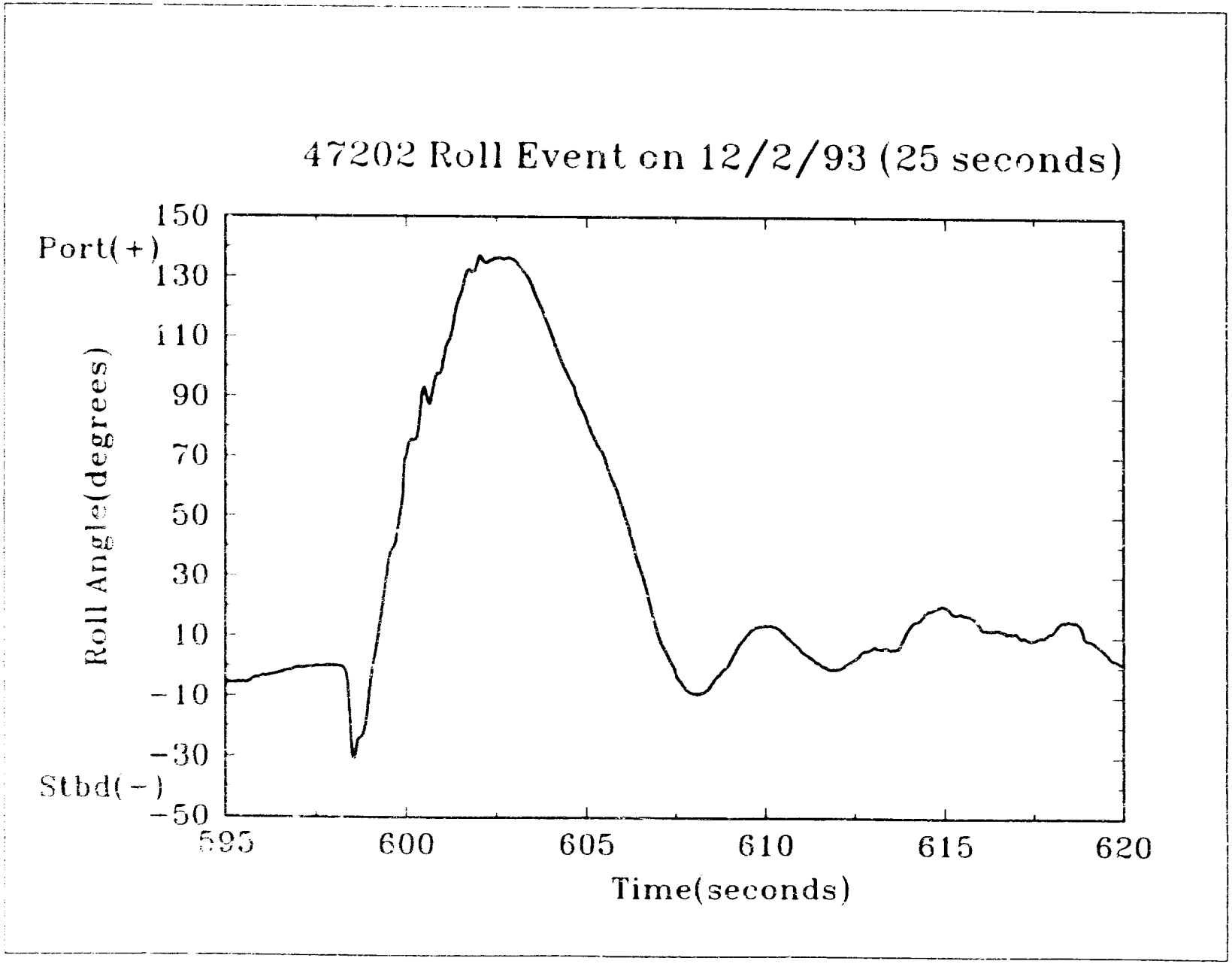


Figure B-22. 47202 Roll Data (25 seconds)

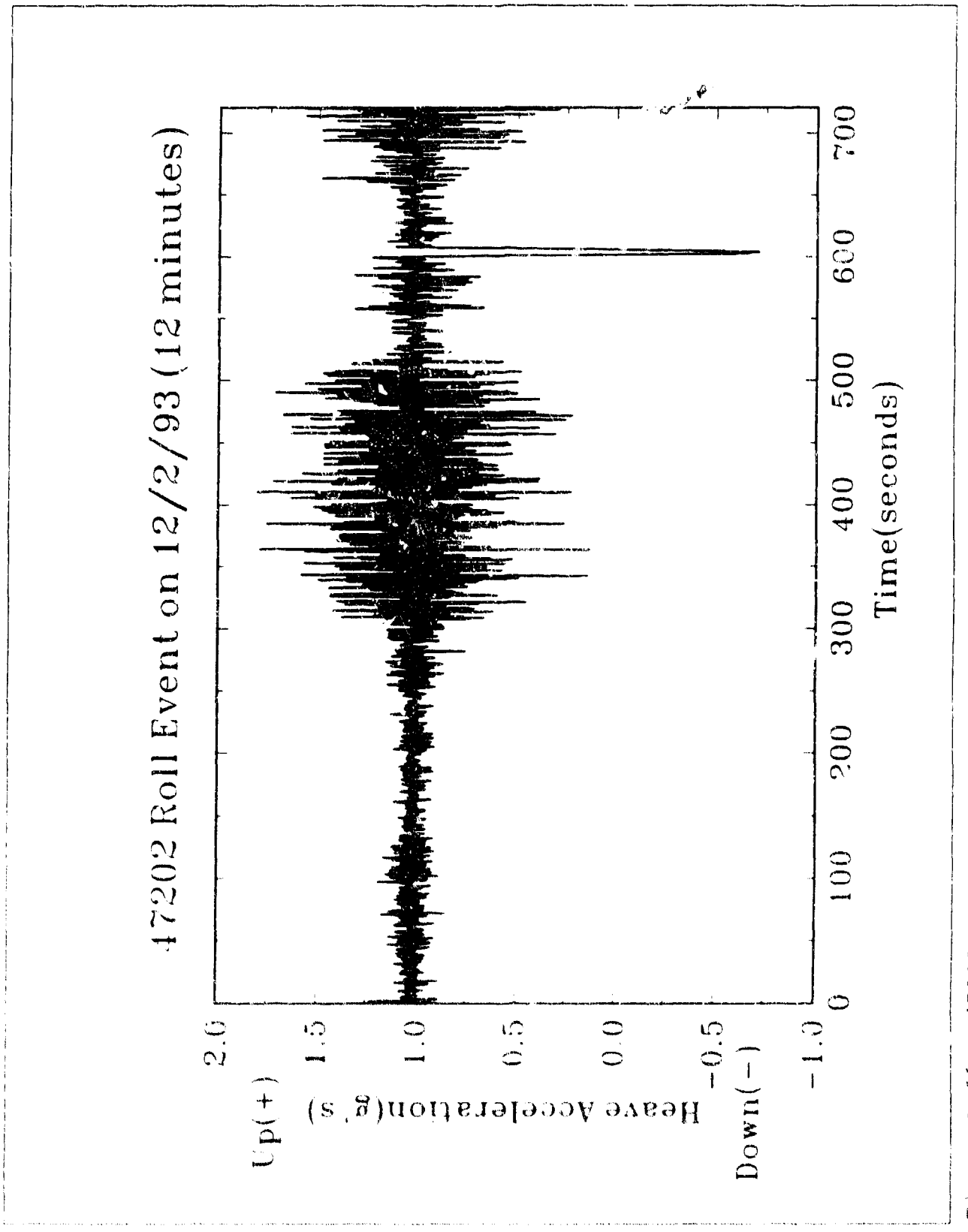


Figure B-23. 47202 Heave Data (12 minutes)

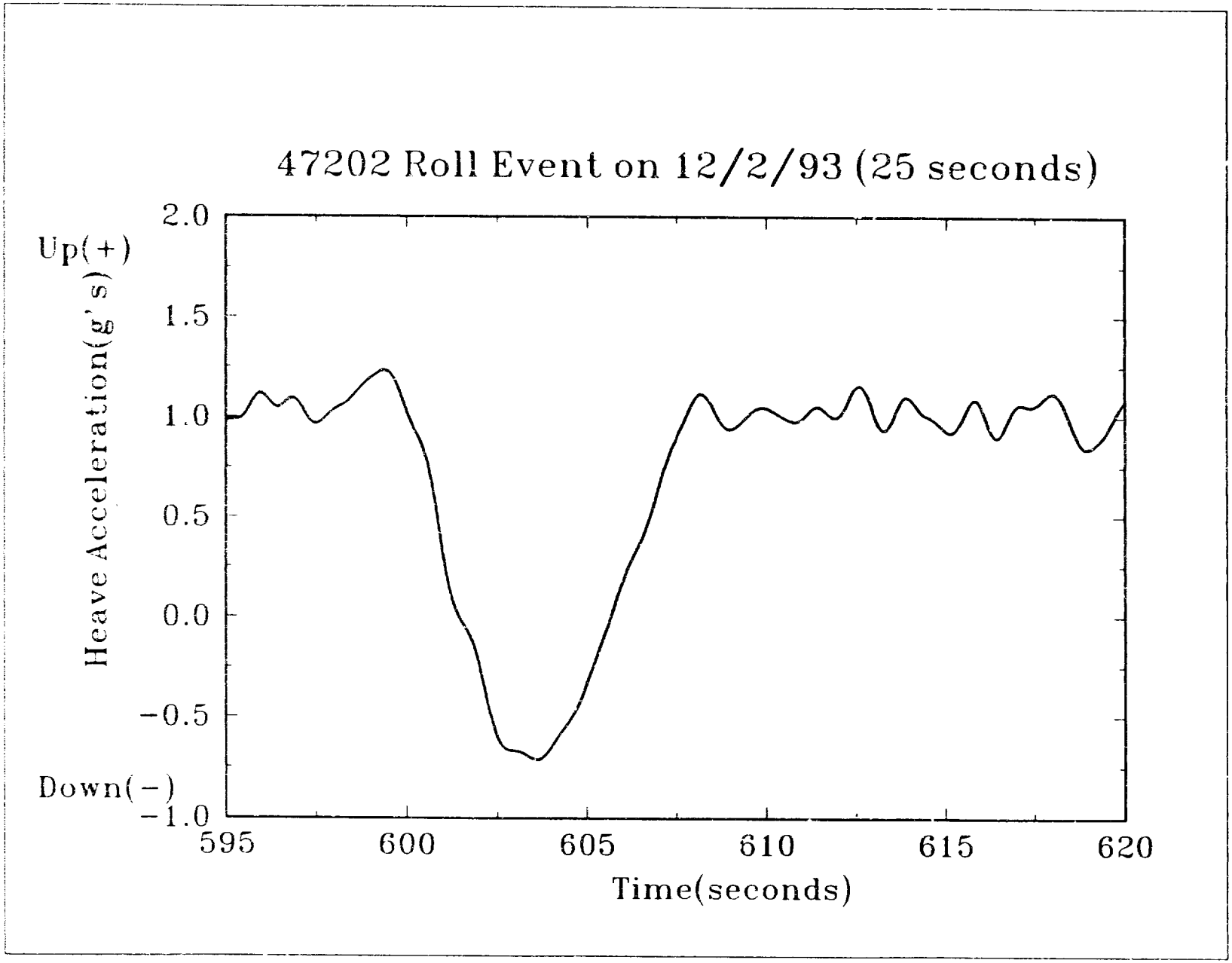


Figure B-24. 47202 Heave Data (25 seconds)

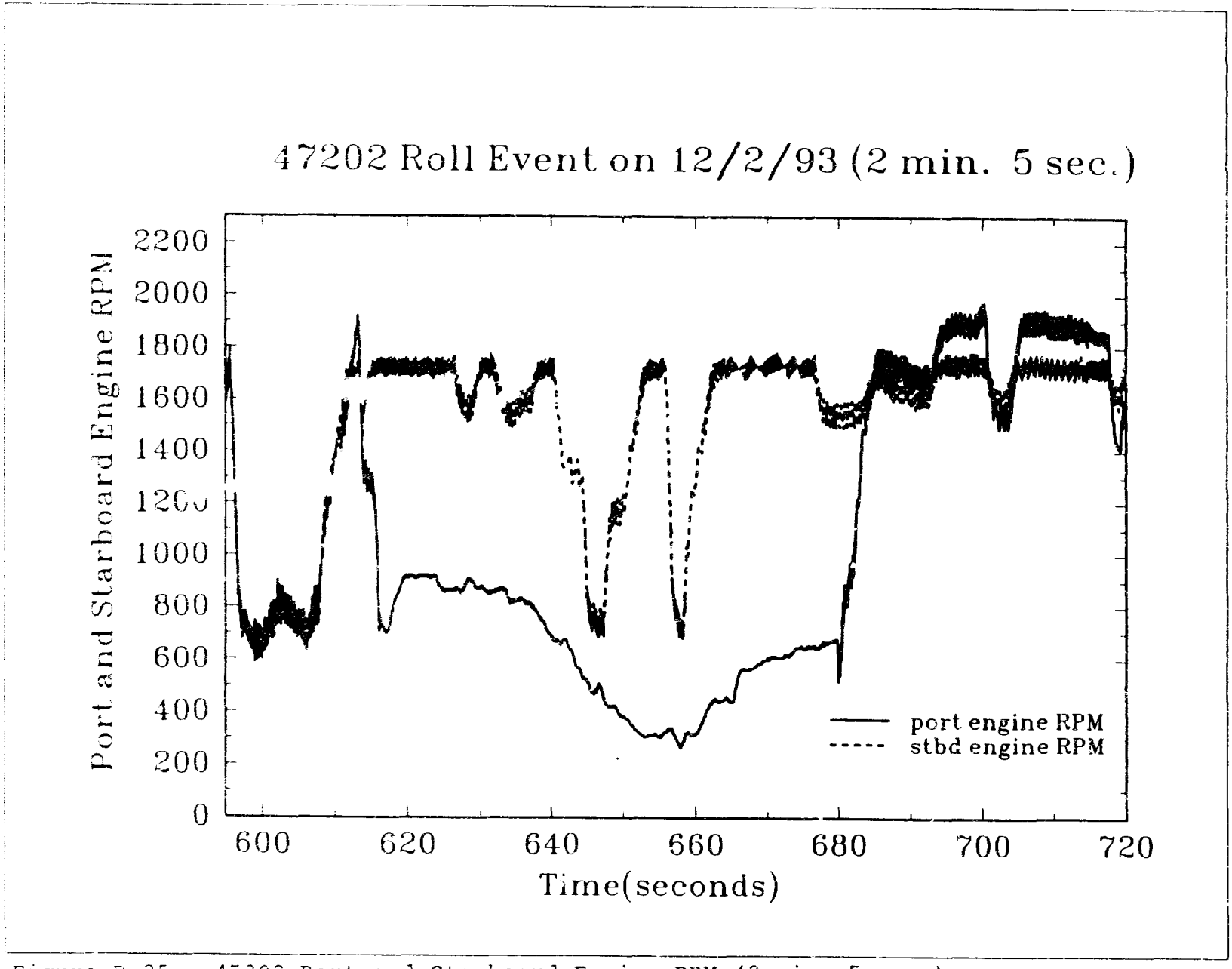
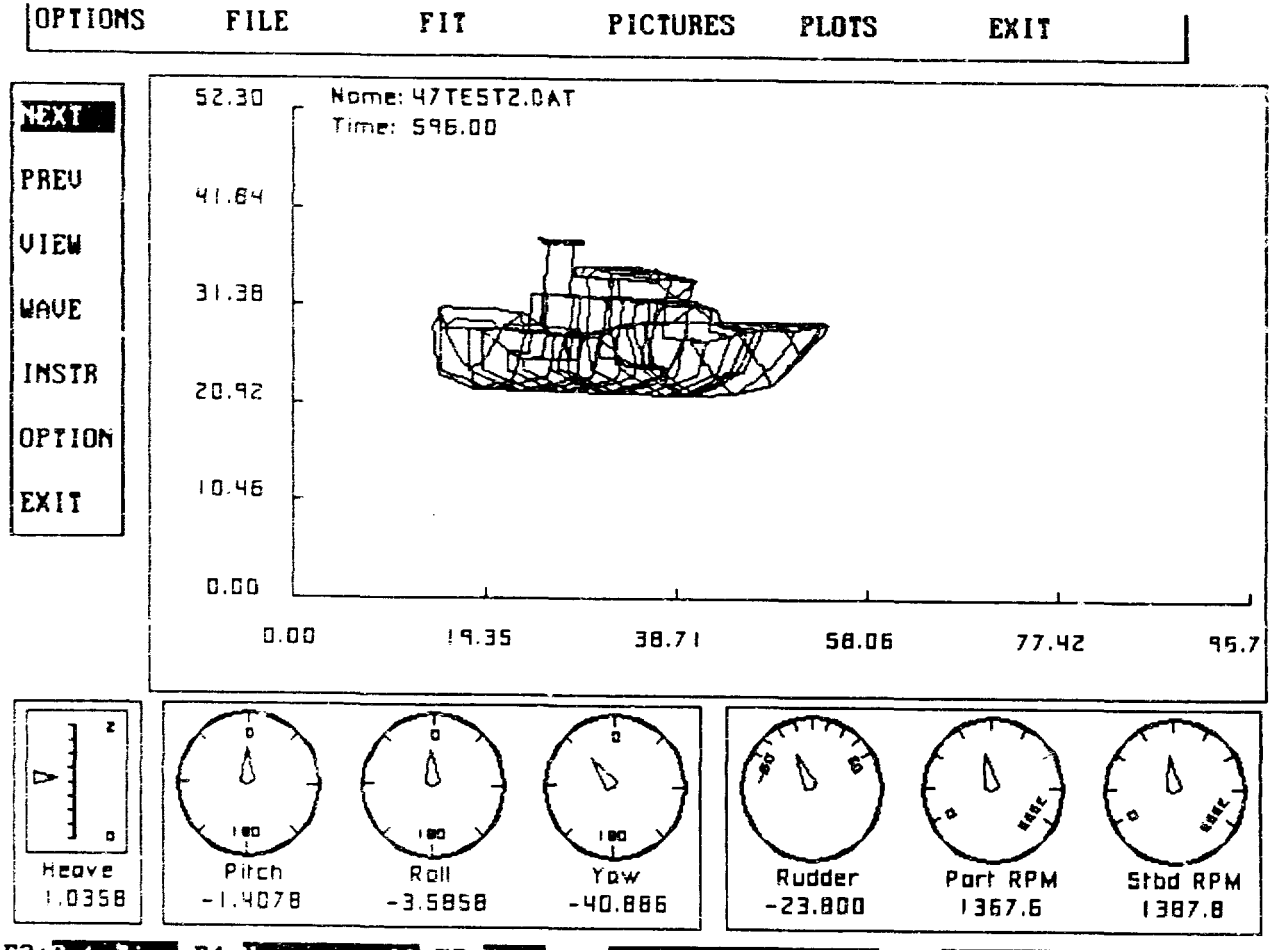


Figure B-25. 47202 Port and Starboard Engine RPM (2 min. 5 sec.)

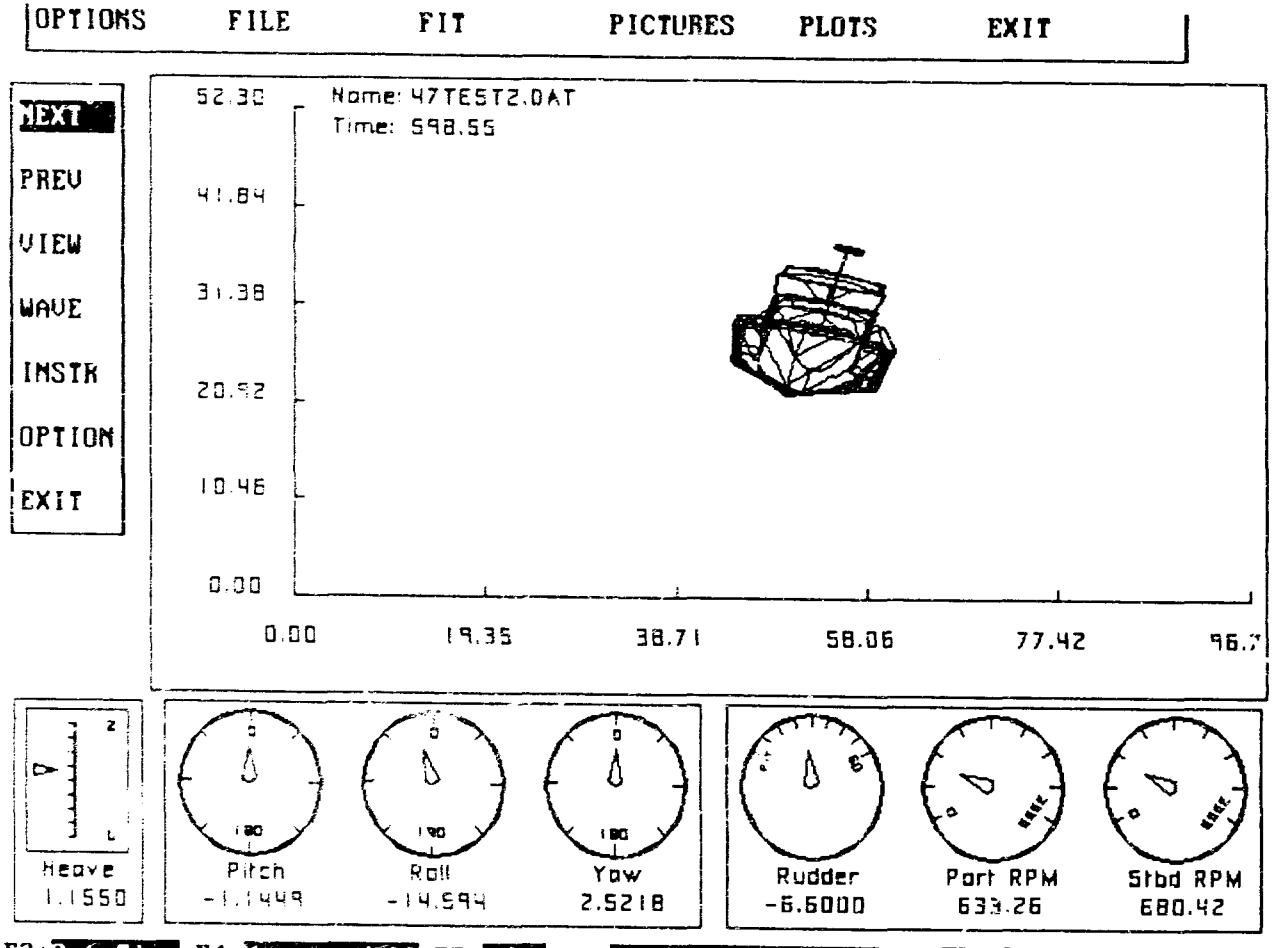
47202 Roll Event on 12/2/93
(-5 seconds)



At 4 seconds before the event engine RPM rapidly decreases from cruising speed to clutch speed. The rudder is at 23 degrees starboard.

Figure B-26. 47202 Roll Event (-5 seconds)

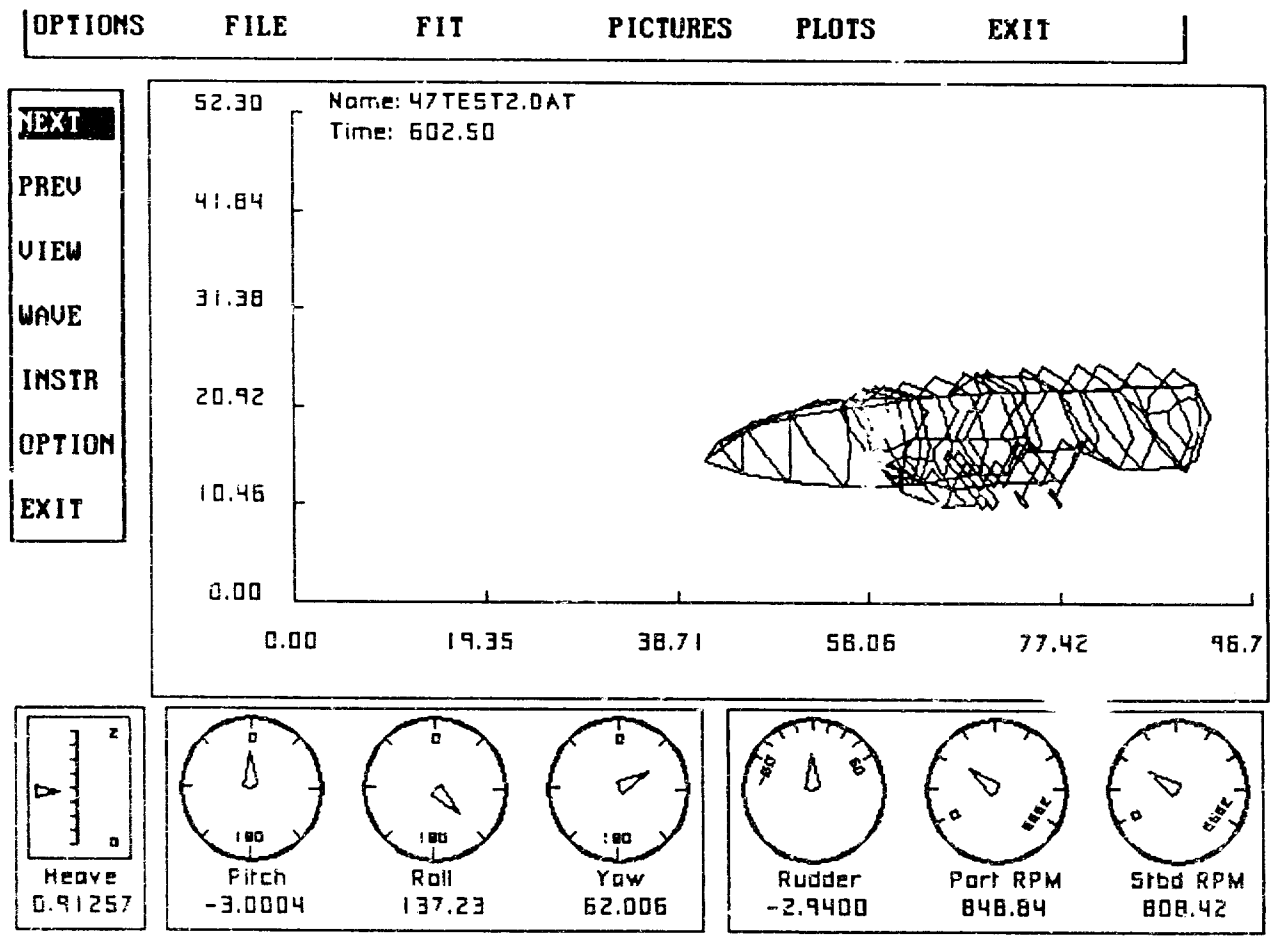
47202 Roll Event on 12/2/93
(-2 seconds)



At 2 seconds before the event the boat experiences a 30 degree roll to starboard (note that roll data was low-pass filtered at 0.5 Hz). The rudder is rapidly changing towards amidship and the egine RPM has decresed to clutch speed.

Figure B-27. 47202 Roll Event (-2 seconds)

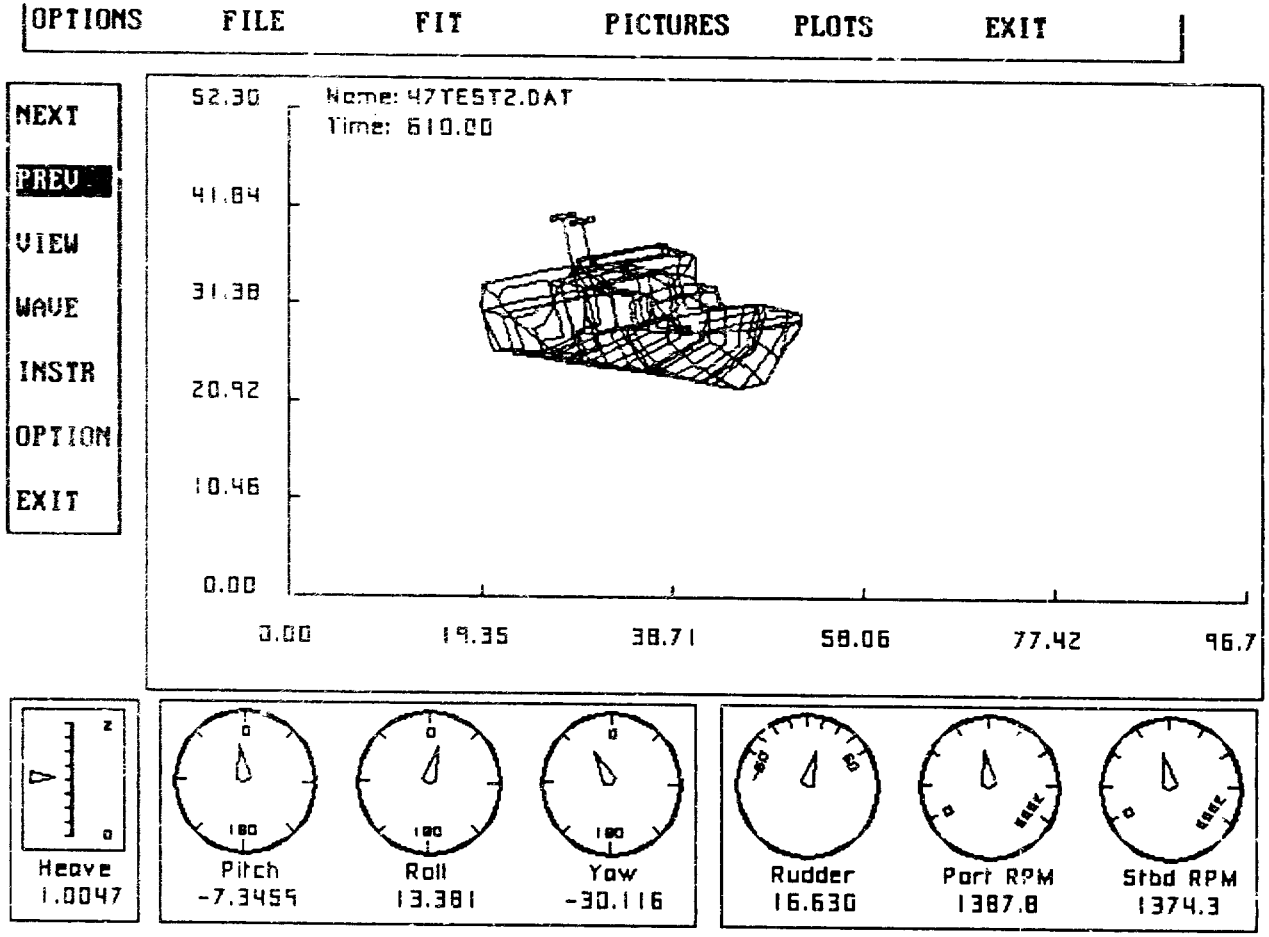
47202 Roll Event on 6/12/94
(+ 3 seconds)



At 3 seconds after the event was triggered (event threshold was set to 60 degrees) the 47202 reaches a maximum roll of 137 degrees. Throughout the roll-over the rudder was held amidship and the egine RPM remained at clutch speed.

Figure B-28. 47202 Roll Event (+3 seconds)

47202 Roll Event on 12/2/93
(+ 10 seconds)



At 10 seconds after the event the rudder rapidly changed to 30 degrees port. Both port and starboard engine RPM increase to approximately 1700 RPM. The port engine RPM then immediately decreased to less than clutch speed and was not matched to the starboard engine (approx. 1700 RPM) until 1 minute later.

Figure B-29. 47202 Roll Event (+10 seconds)

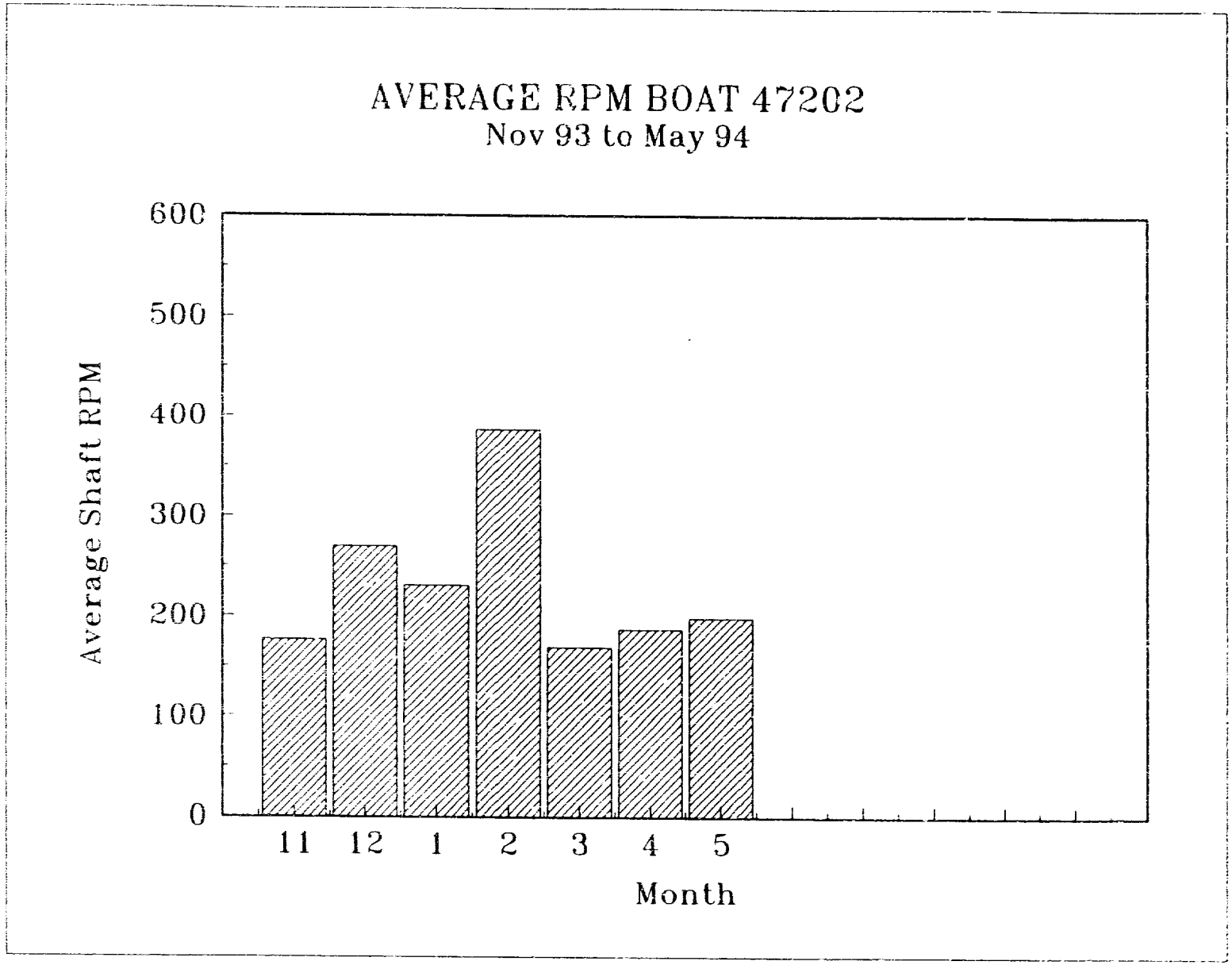


Figure B-30. 47202 Average RPM

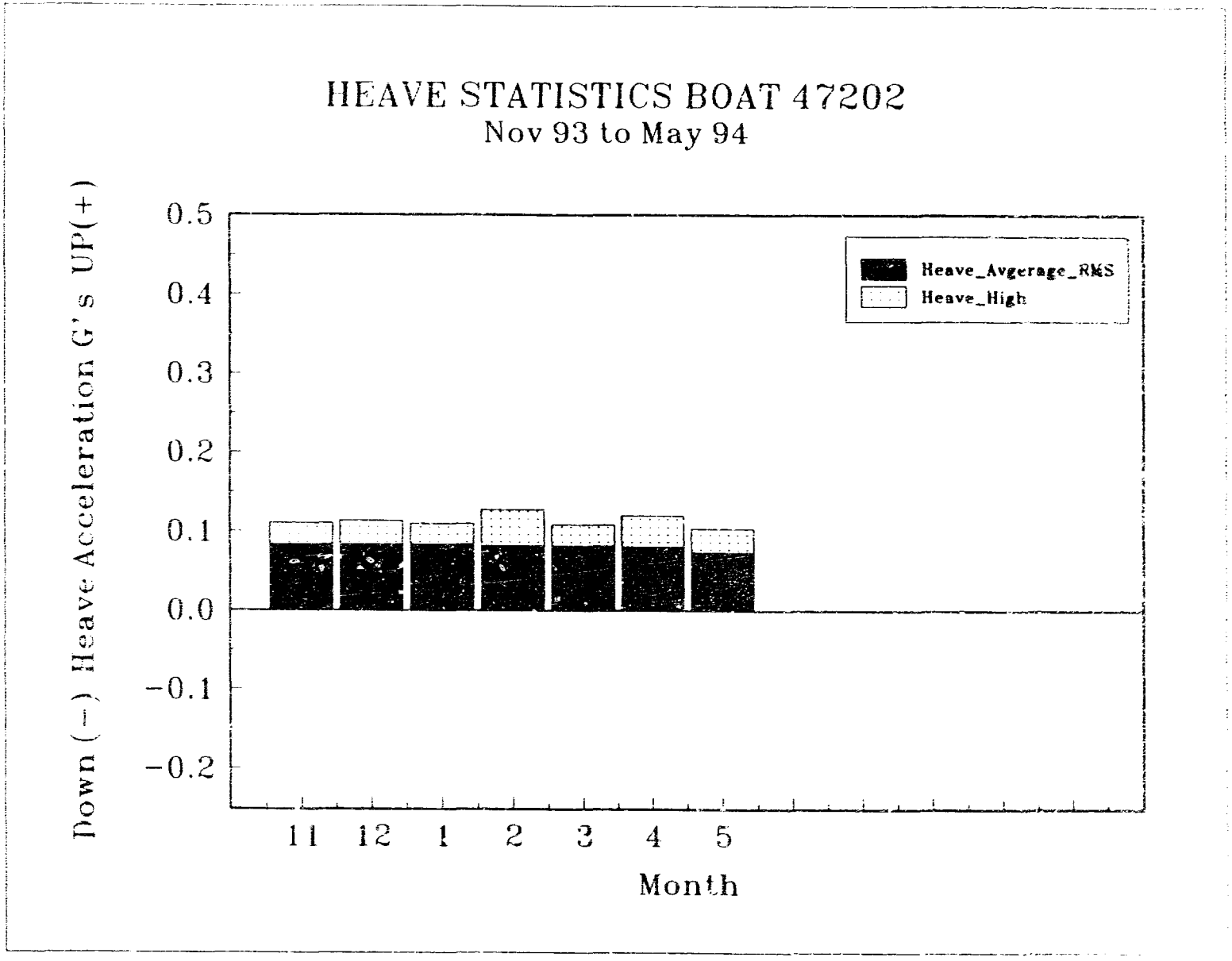


Figure B-31. 47202 Heave Statistics

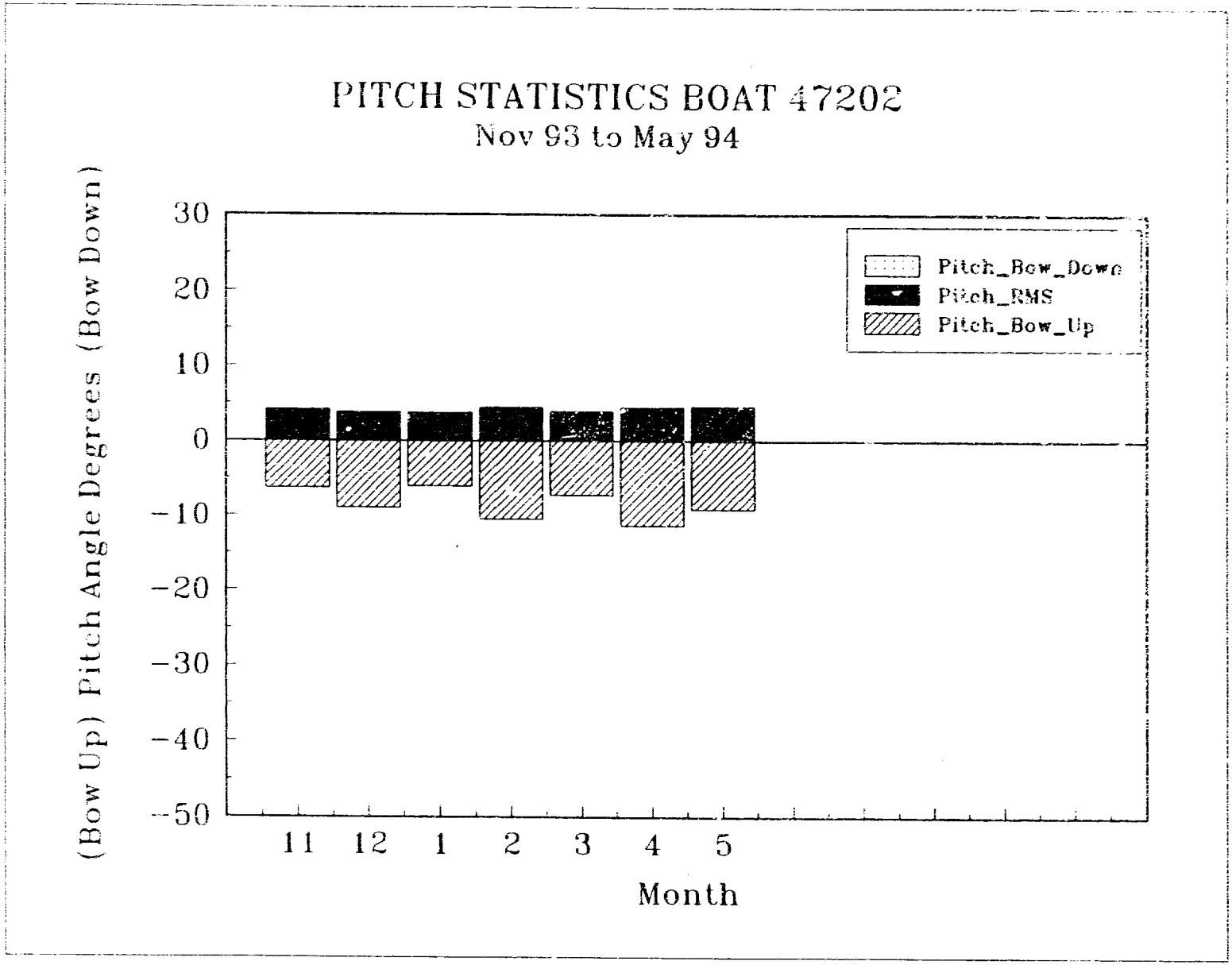


Figure B-32. 47202 Pitch Statistics

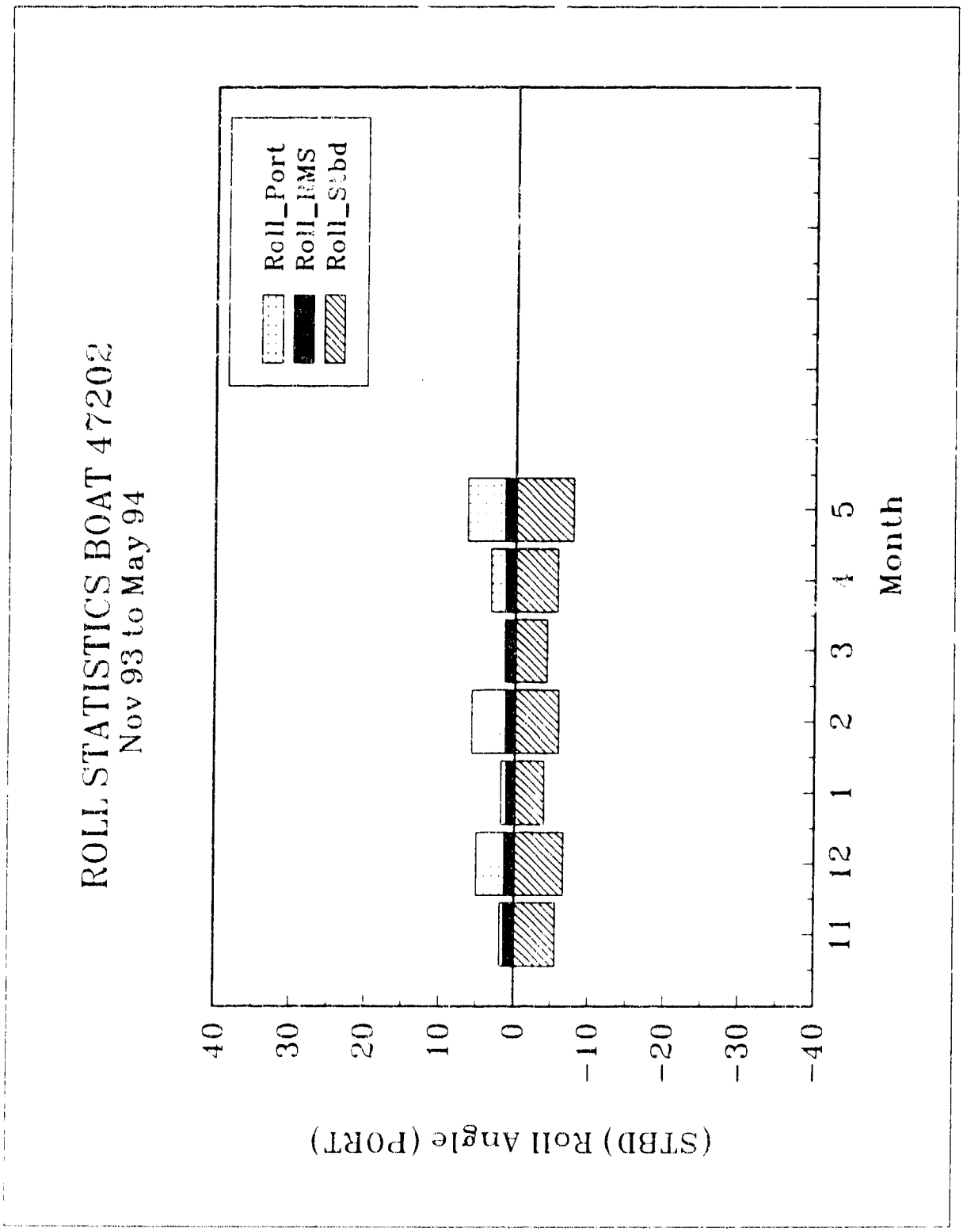


Figure B-33. 47202 Roll Statistics

APPENDIX C

47203 DATA RESULTS

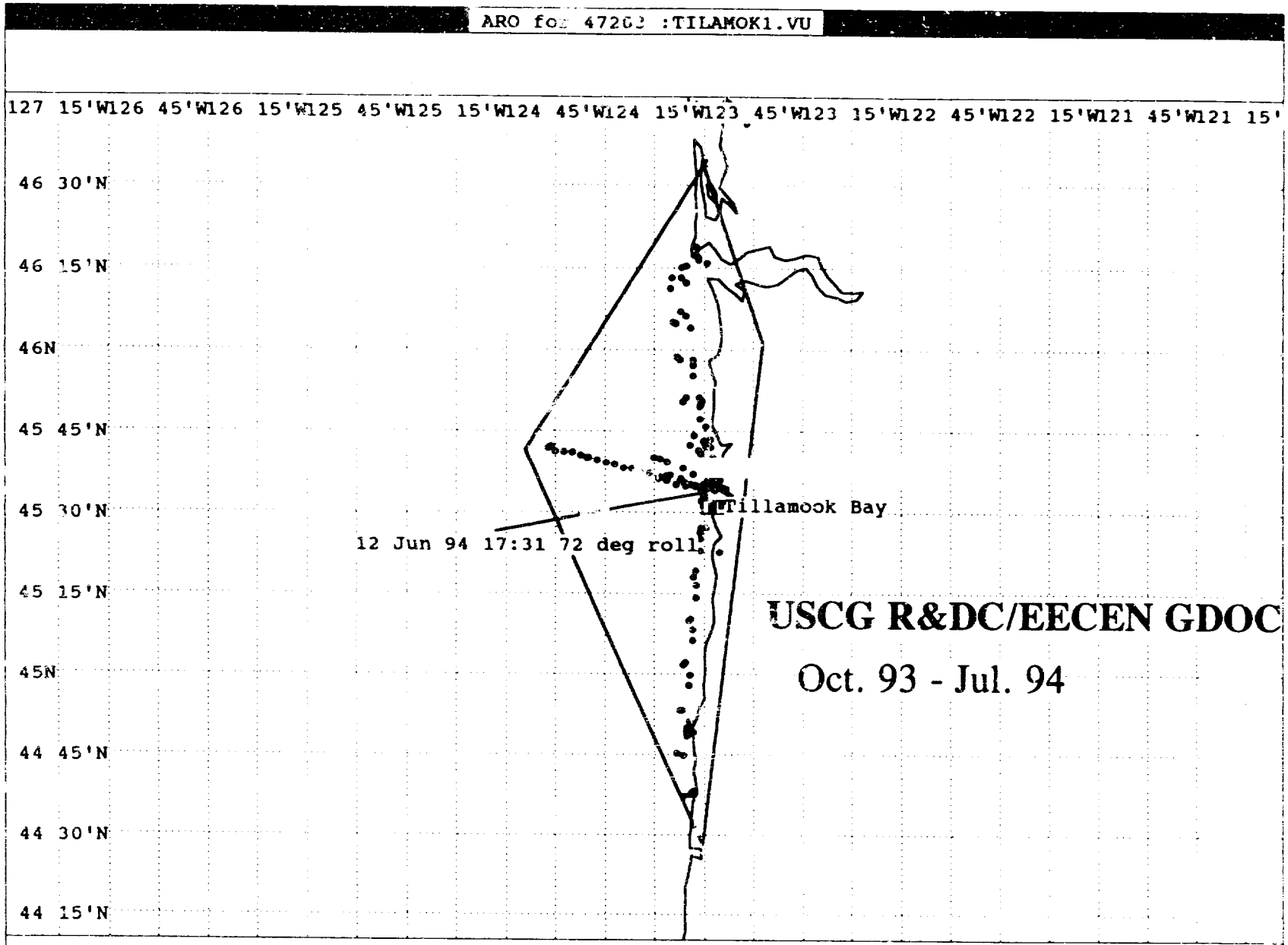


Figure C-1. Area of Recorded Operations for 47203

TABLE C-I. 47203 EVENT SUMMARY TABLE

Summary of Data Collected with the MDR

Boat: 47203
Date: 12 JUN 94
Dock Departure (Shore-tie Disconnected): 13:32
Time of Event: 17:31
Location: 45 deg, 33.27 min. lat.; 123 deg, 54.32 min. long.
Maximum Roll Angle Detected: 72 degrees
Time Spent Past 90 Degrees: N.A.
Time Spent Past 45 Degrees: 2.80 seconds
Stbd Engine RPM:
- Before Event - decreasing from 1620 to 1000 RPM (just prior to event)
- During Event - 1600 RPM
- After Event - decreasing from 1600 to 950 RPM

Port Engine RPM:
- Before Event - decreasing from 1850 to 850 RPM (just prior to event)
- During Event - 1800 RPM
- After Event - decreasing from 1800 to 900 RPM

Rudder Angle:
- Before Event - 5 degrees port
- During Event - 0 degrees
- After Event - changing rapidly to 30 degrees starboard

Heading:
- Before Event - 360 degrees
- After Event - 320 degrees

Pitch: Bow up

Note: Ship's position captured 28 minutes before event; boat was underway for 4½ hours.

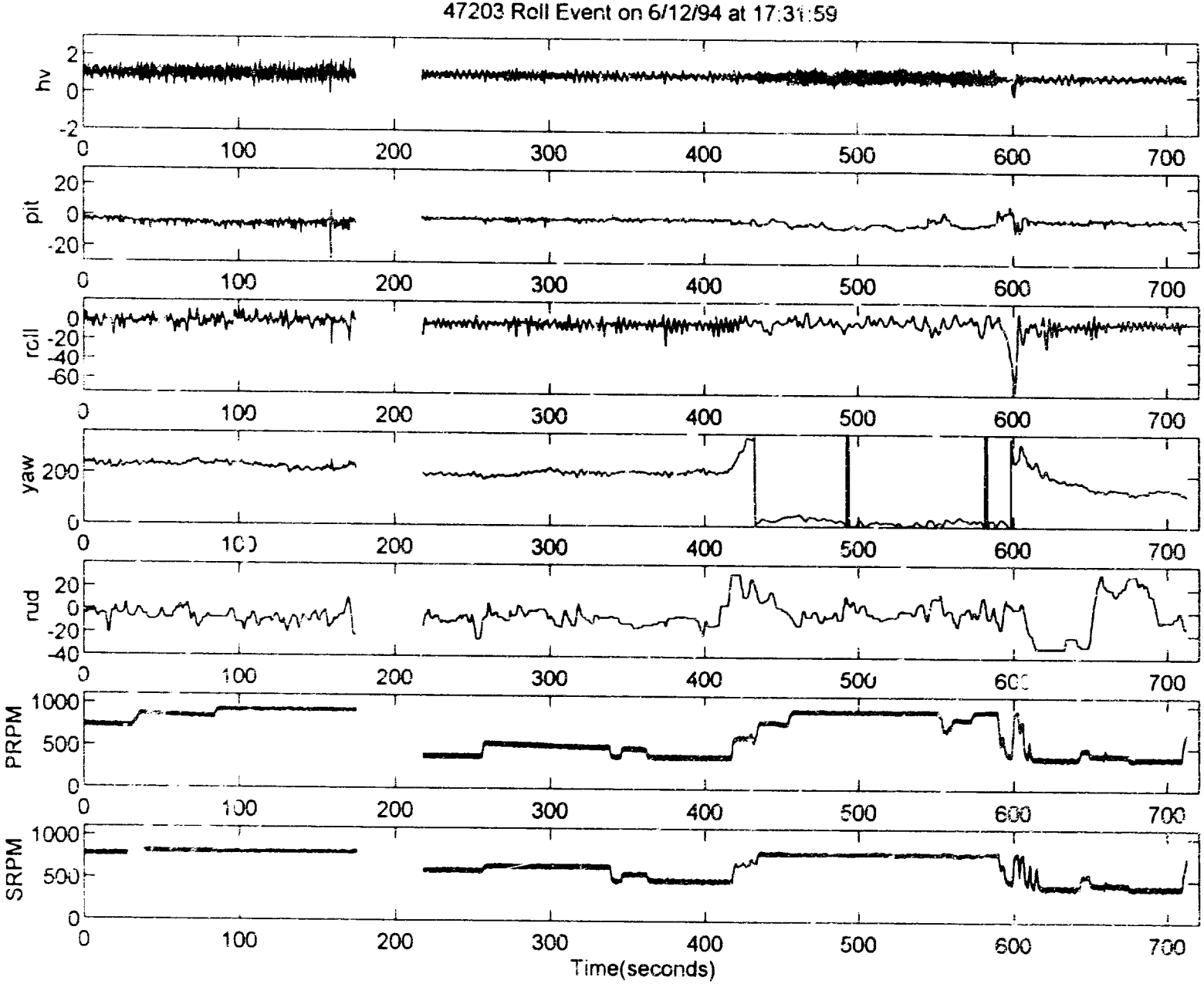


Figure C-2. 47203 Roll Event

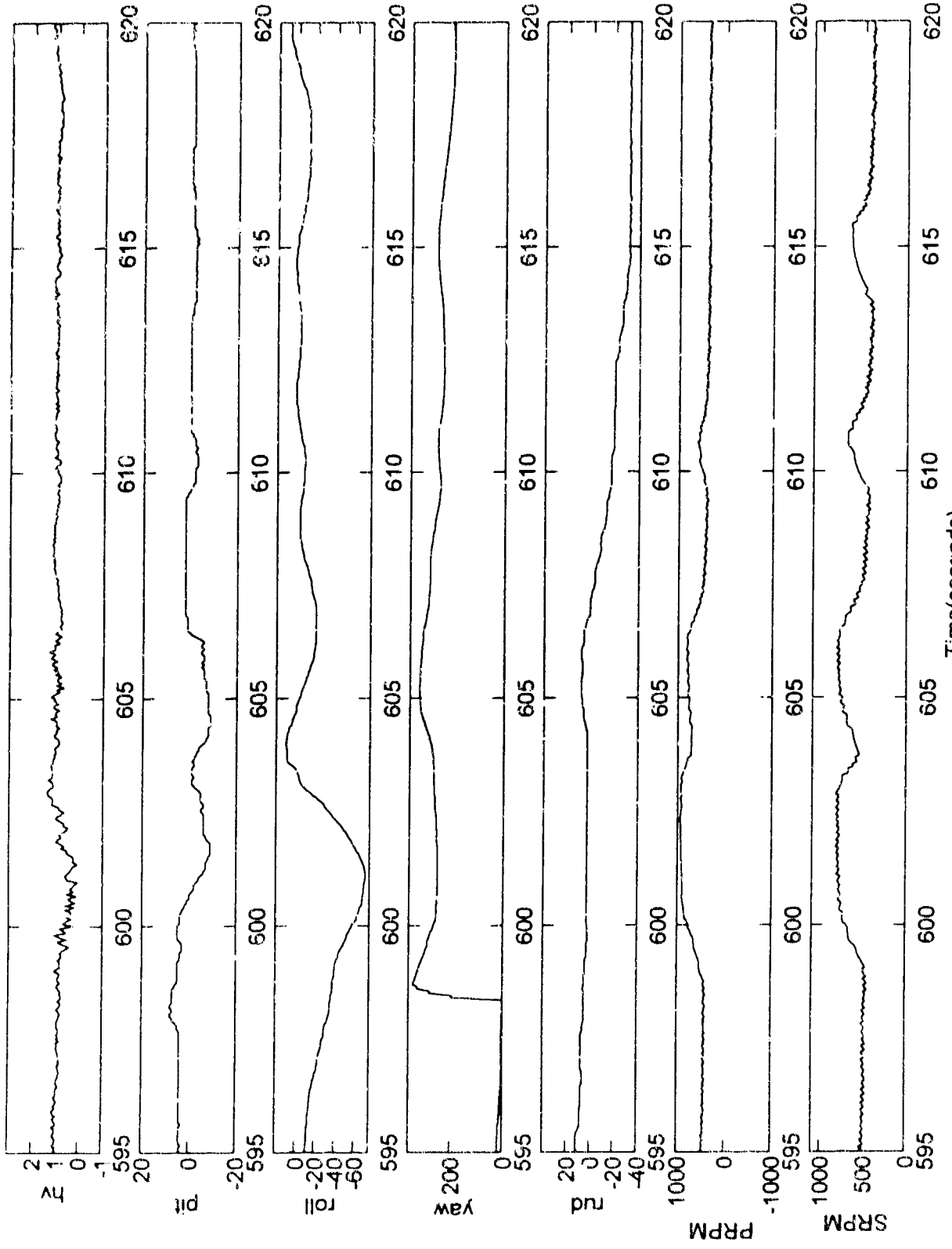


Figure C-3. 47203 Roll Event (25 seconds)

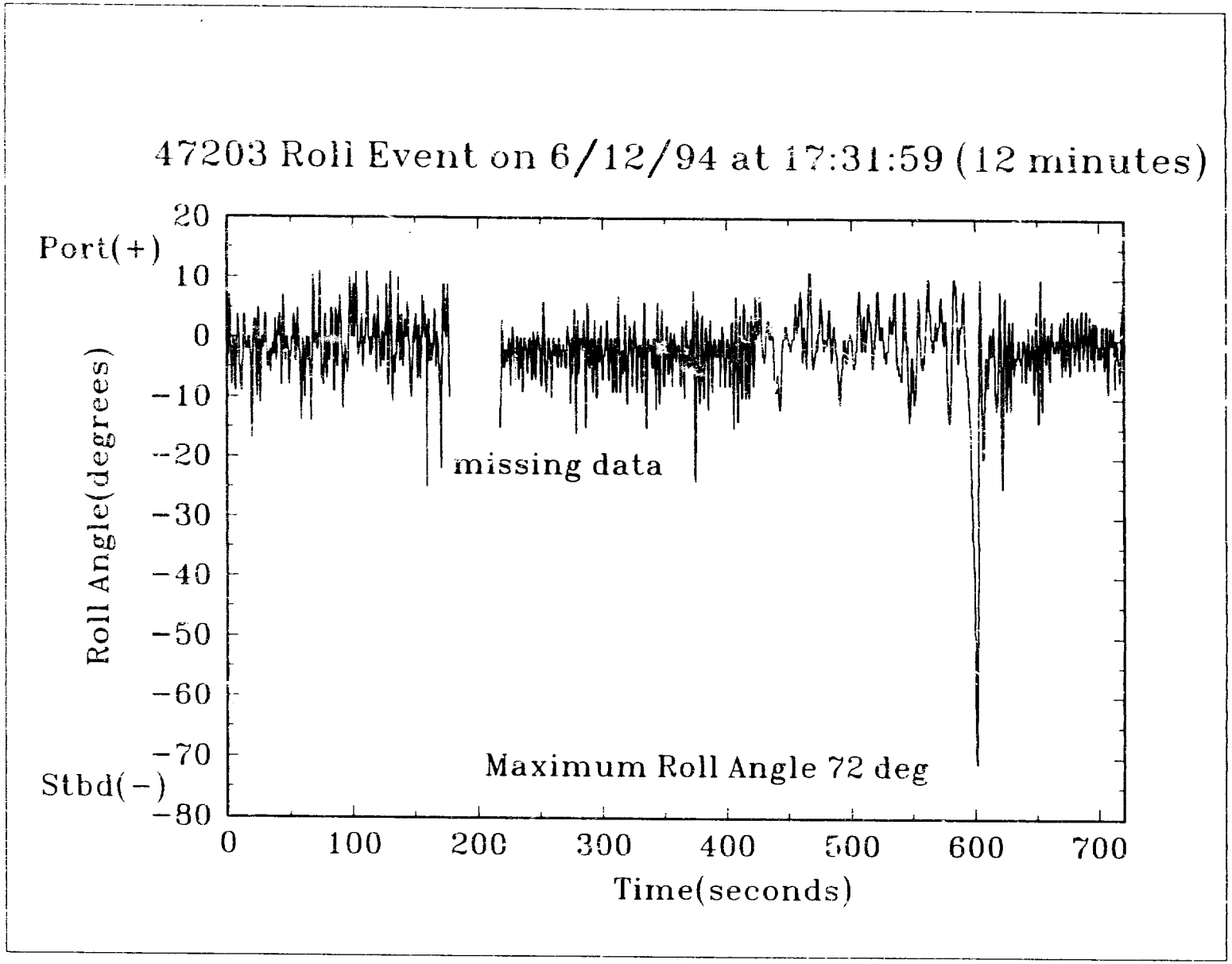


Figure C-4. 47203 Roll Event, Roll Angle (12 minutes)

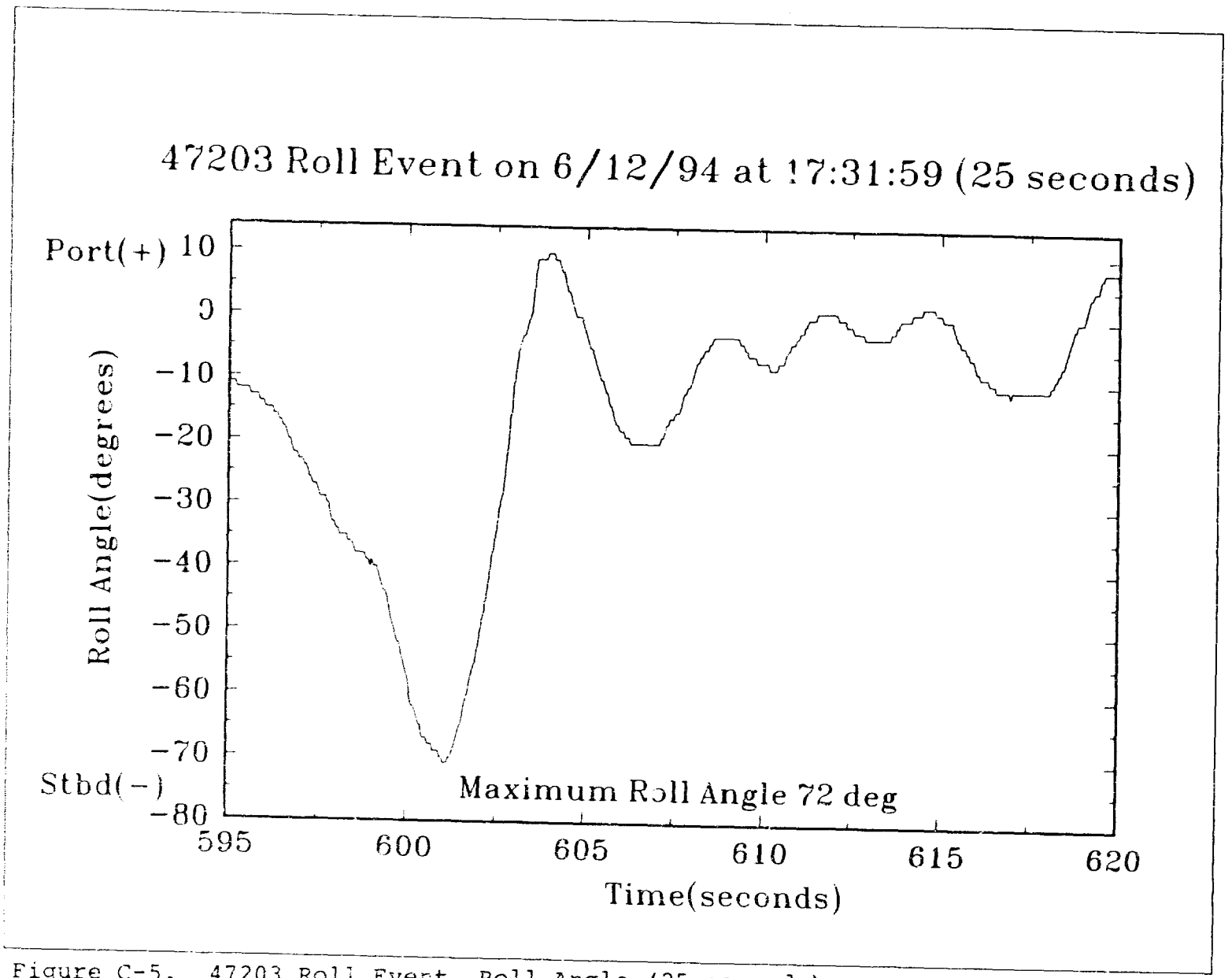


Figure C-5. 47203 Roll Event, Roll Angle (25 seconds)

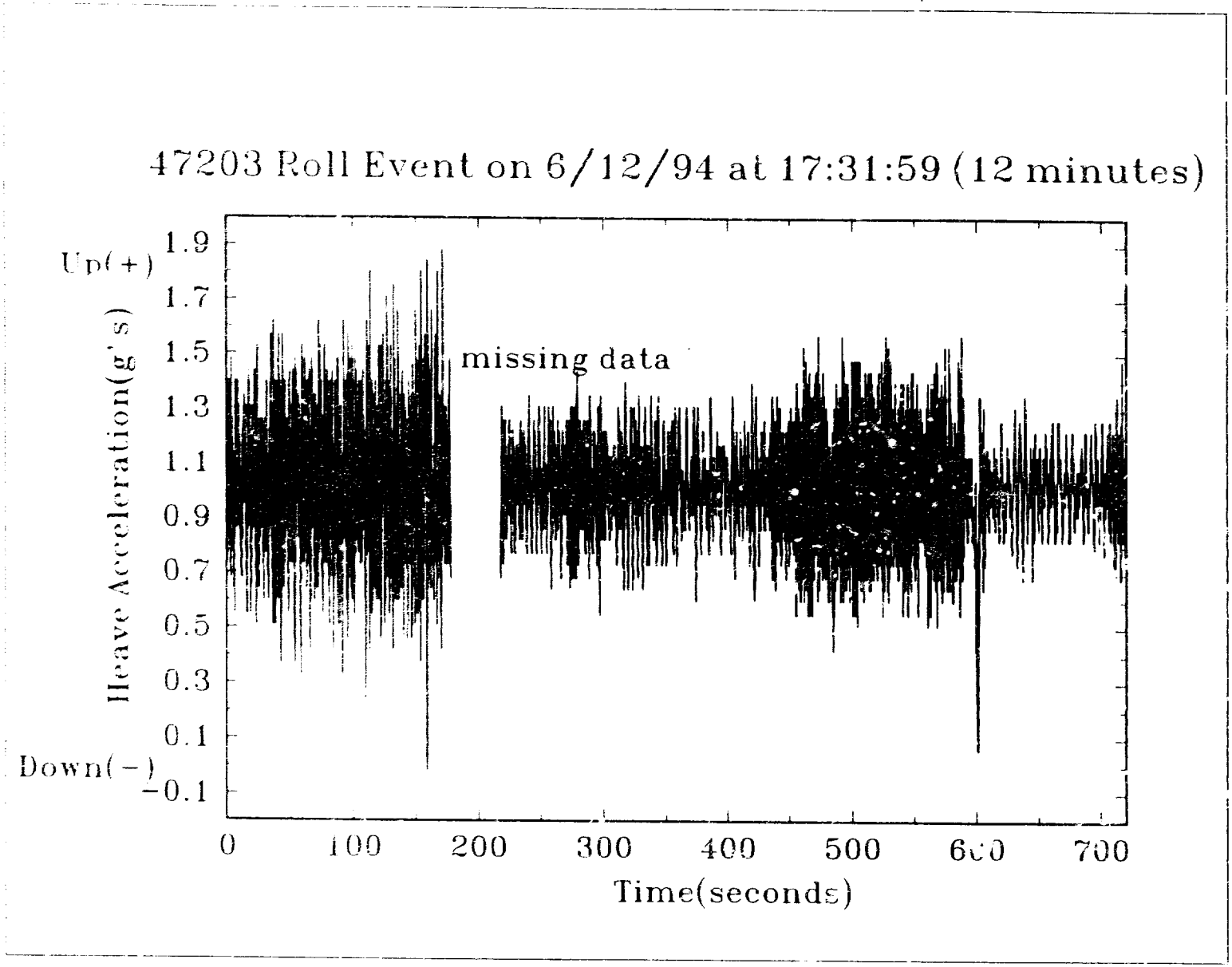


Figure C-6. 47203 Roll Event, Heave (12 minutes)

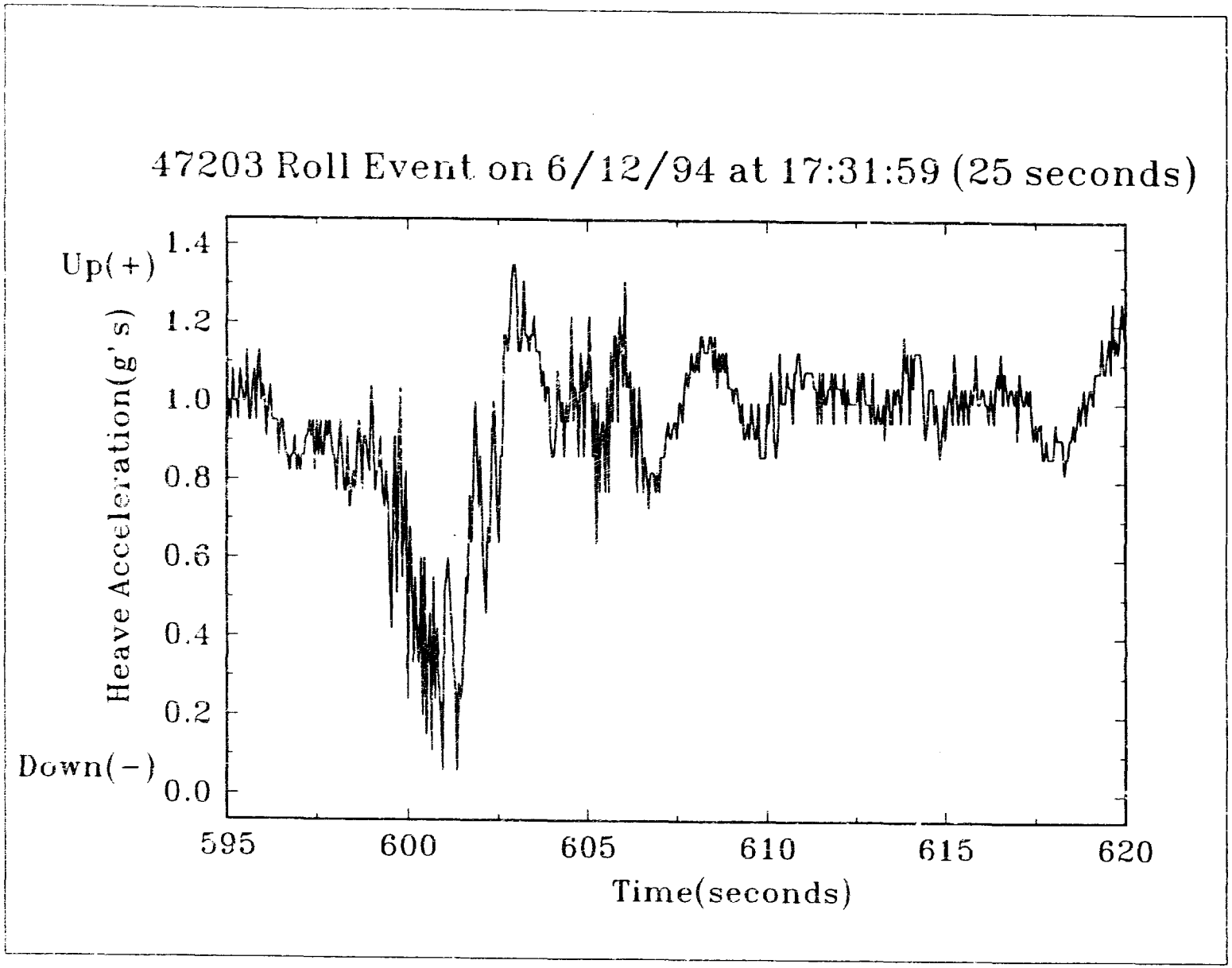


Figure C-7. 47203 Roll Event, Heave (25 seconds)

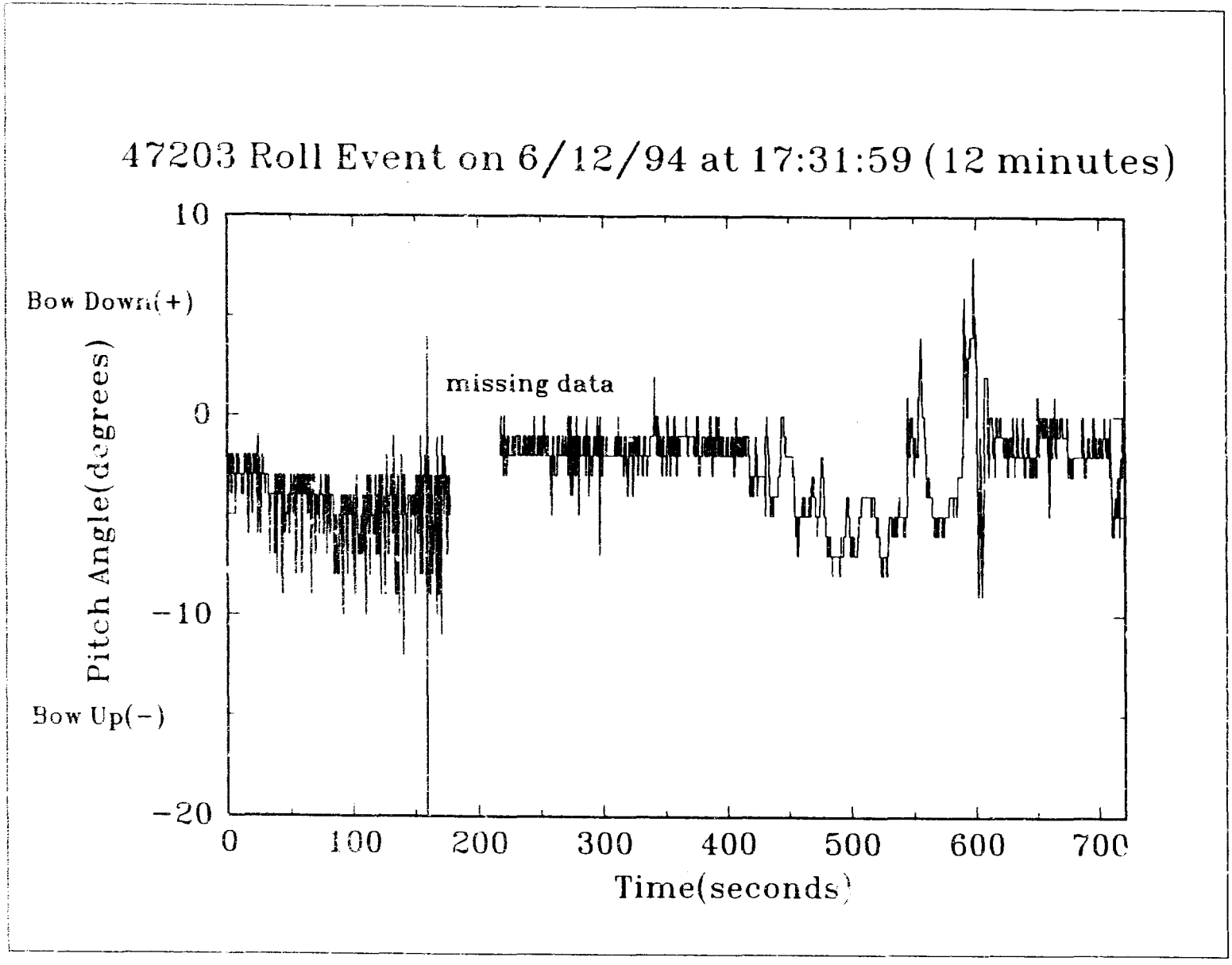


Figure C-8. 47203 Roll Event, Pitch Angle (12 minutes)

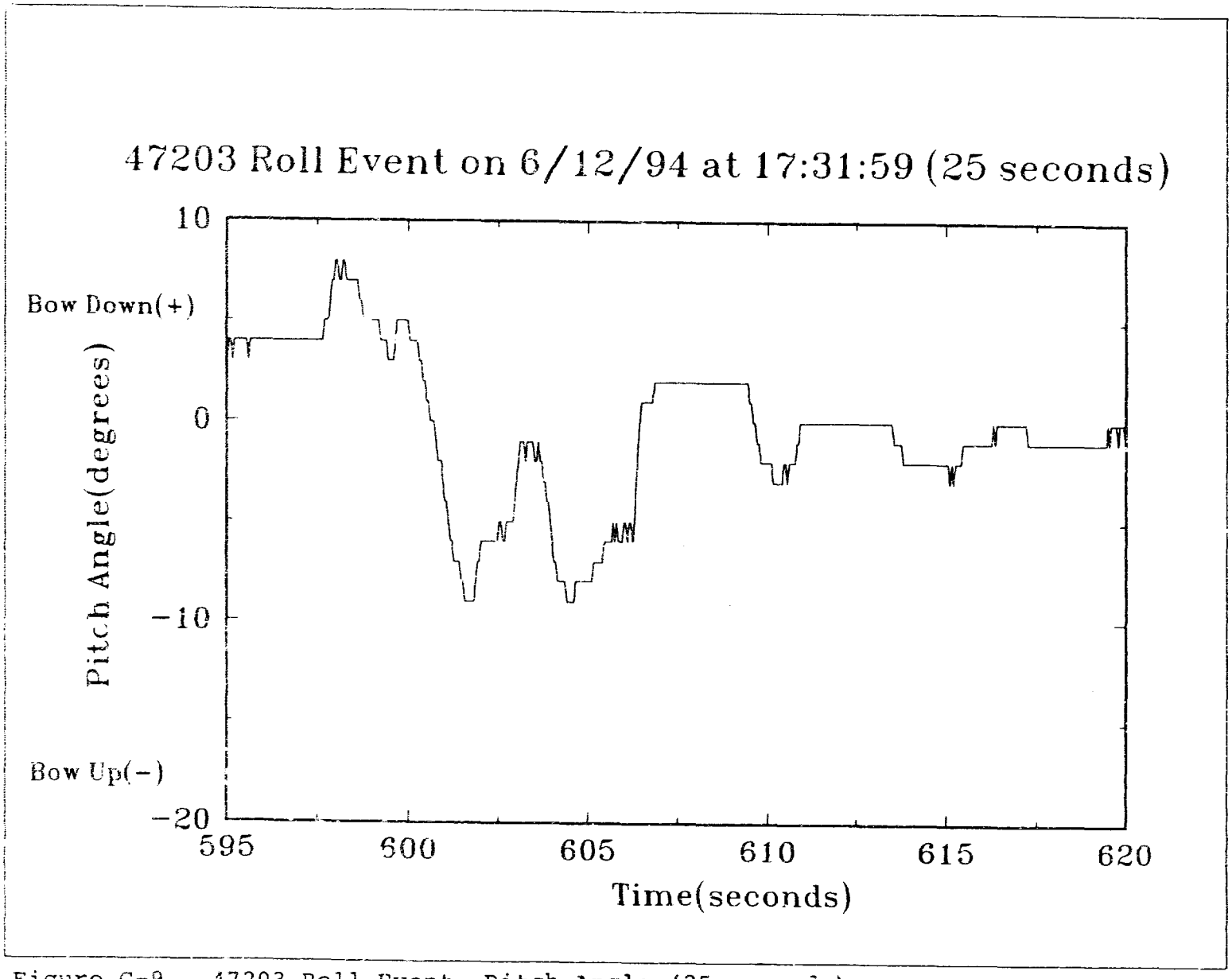


Figure C-9. 47203 Roll Event, Pitch Angle (25 seconds)

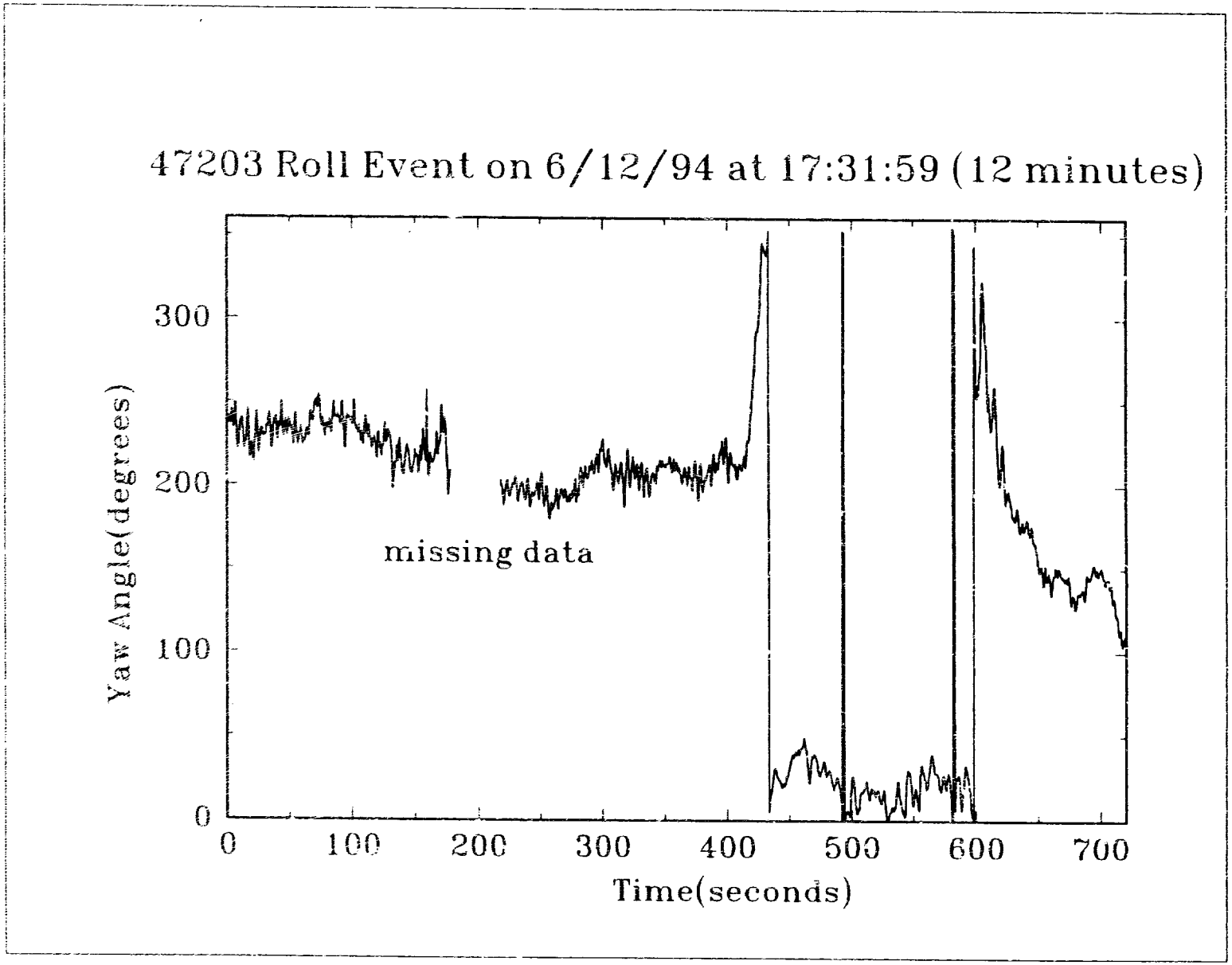


Figure C-10. 47203 Roll Event, Yaw Angle (12 minutes)

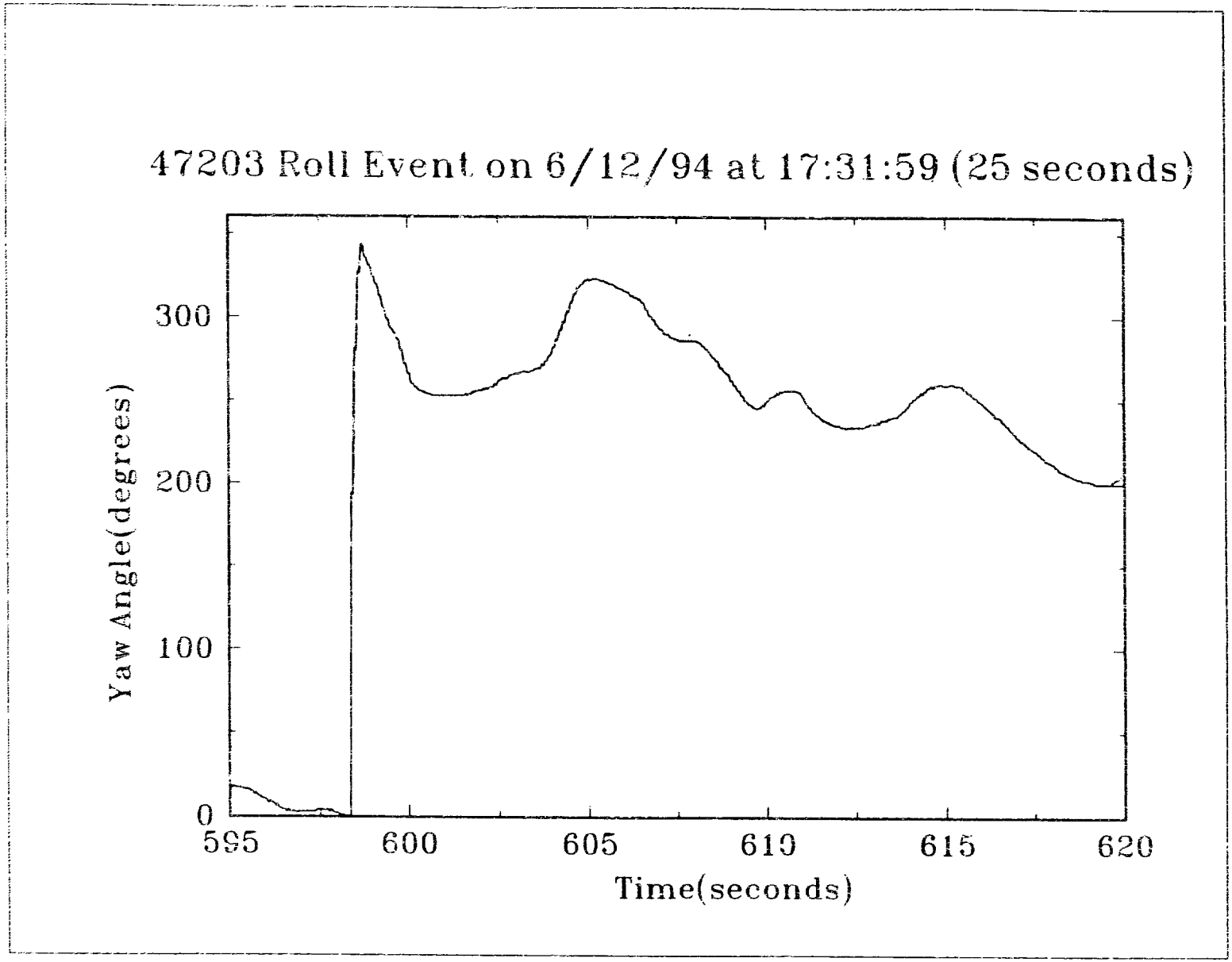


Figure C-11. 47203 Roll Event, Yaw Angle (25 seconds)

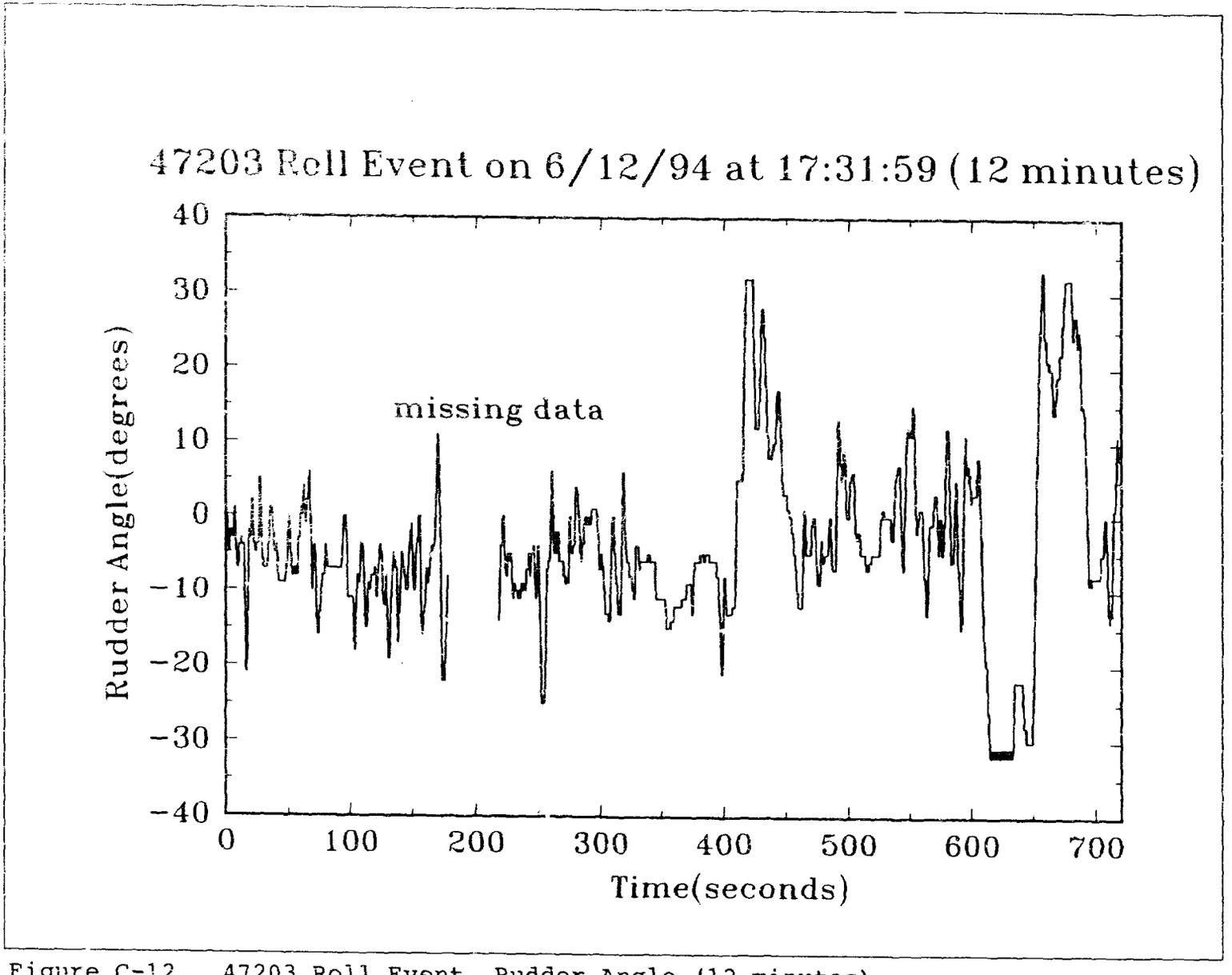


Figure C-12. 47203 Roll Event, Rudder Angle (12 minutes)

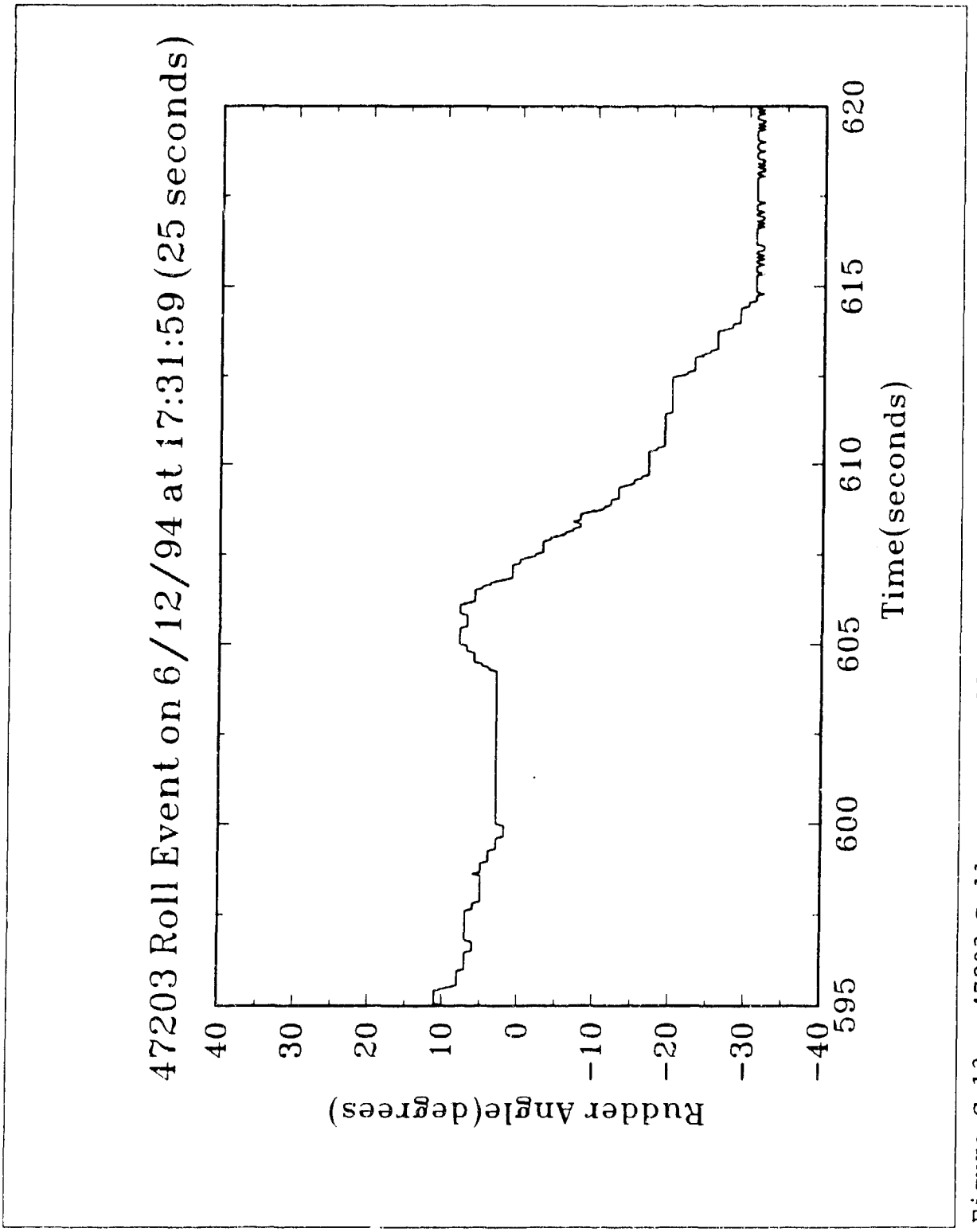


Figure C-13. 47203 Roll Event, Rudder Angle (25 seconds)

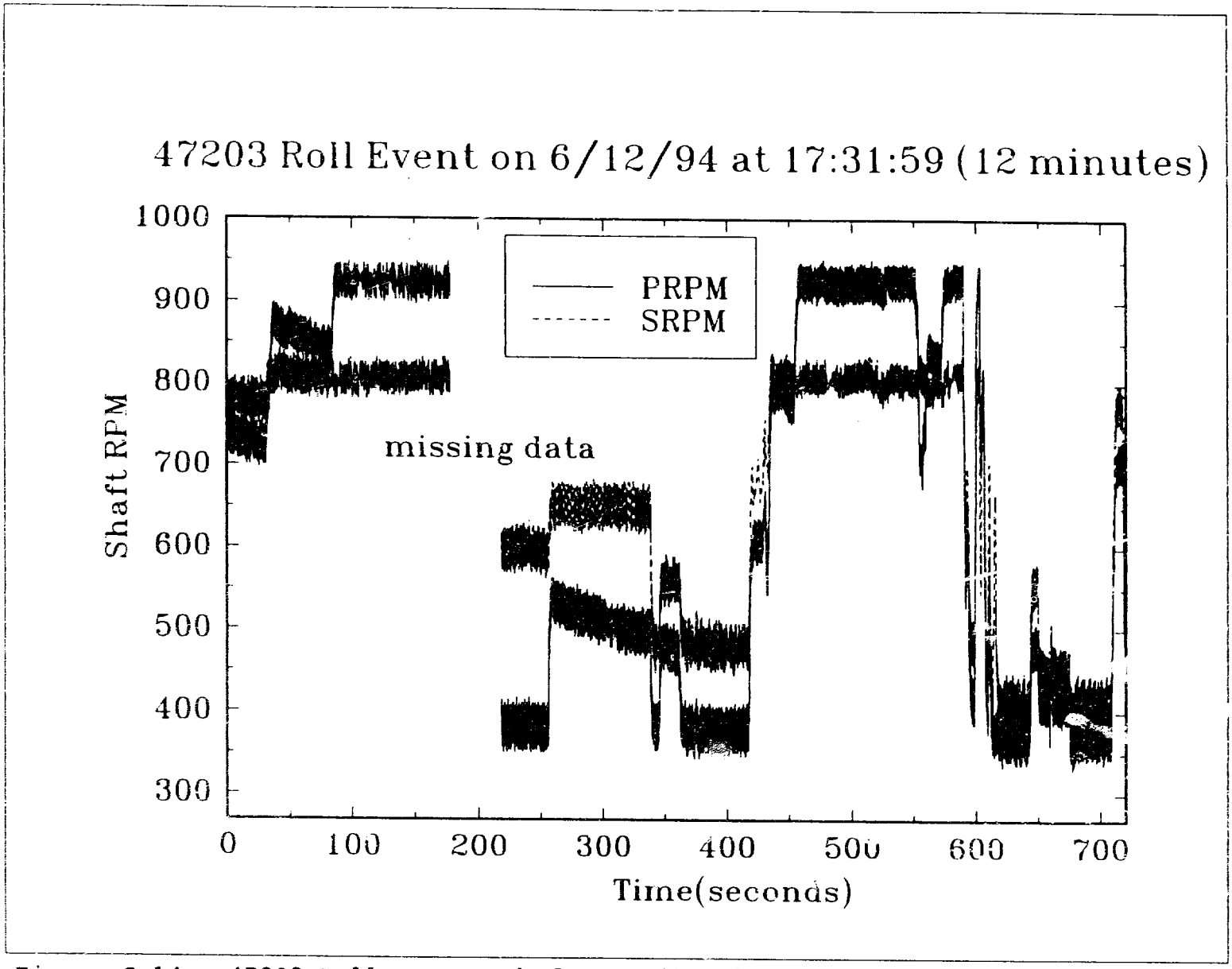


Figure C-14. 47203 Roll Event, Shaft RPM (12 minutes)

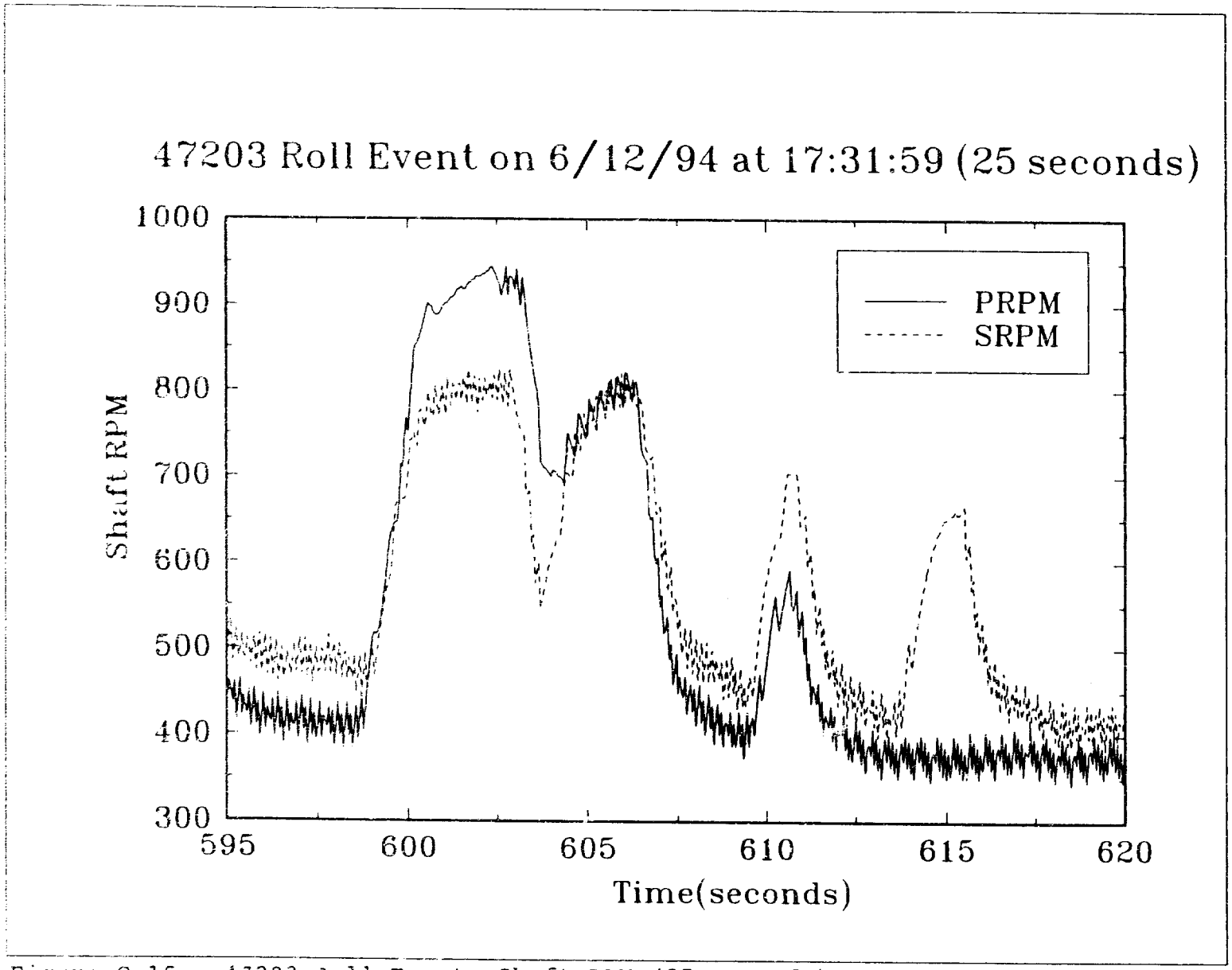
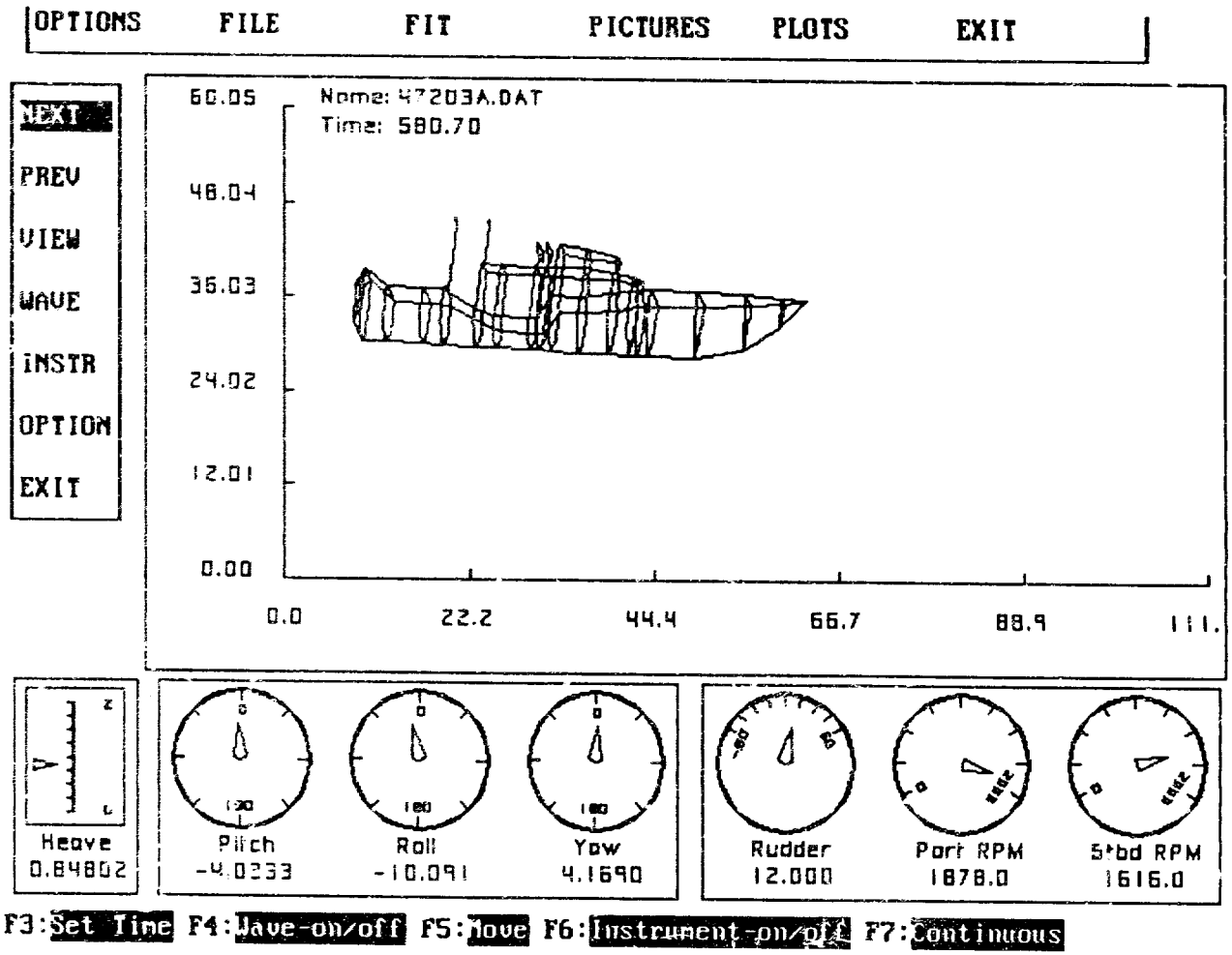


Figure C-15. 47203 Roll Event, Shaft RPM (25 seconds)

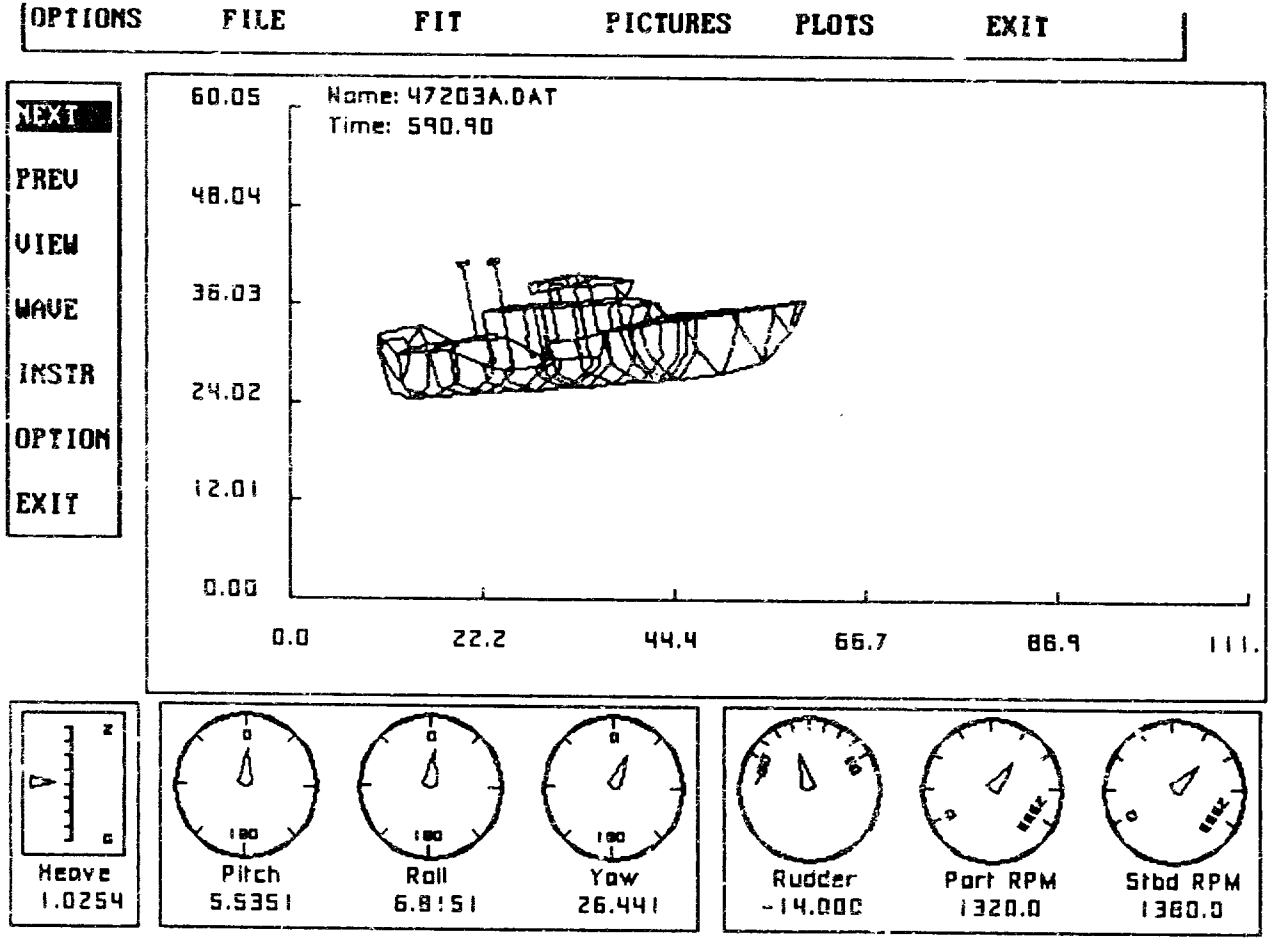
47203 Roll Event on 6/12/94
(-20 seconds)



At 20 seconds before the event the 47203 is near full throttle. The starboard RPM is running approximately 250 RPM less than the port engine.

Figure C-16. 47203 Roll Event (-20 seconds)

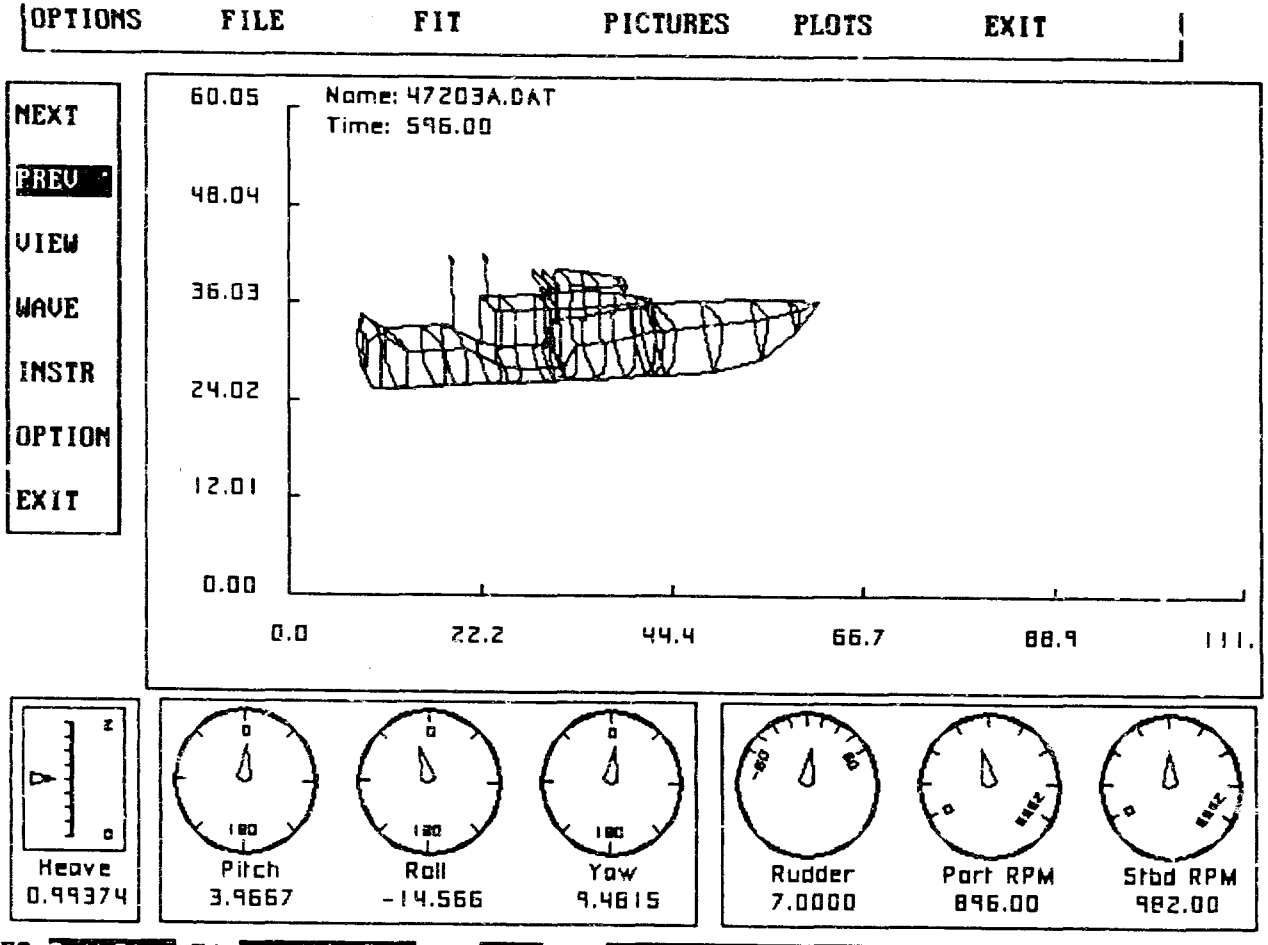
47203 Roll Event on 6/12/94
(-10 seconds)



At 10 seconds before the event both port and starboard engine RPM decrease rapidly. The 47203 experiences a 7 degree roll to port before going into the 72 degree starboard roll sequence.

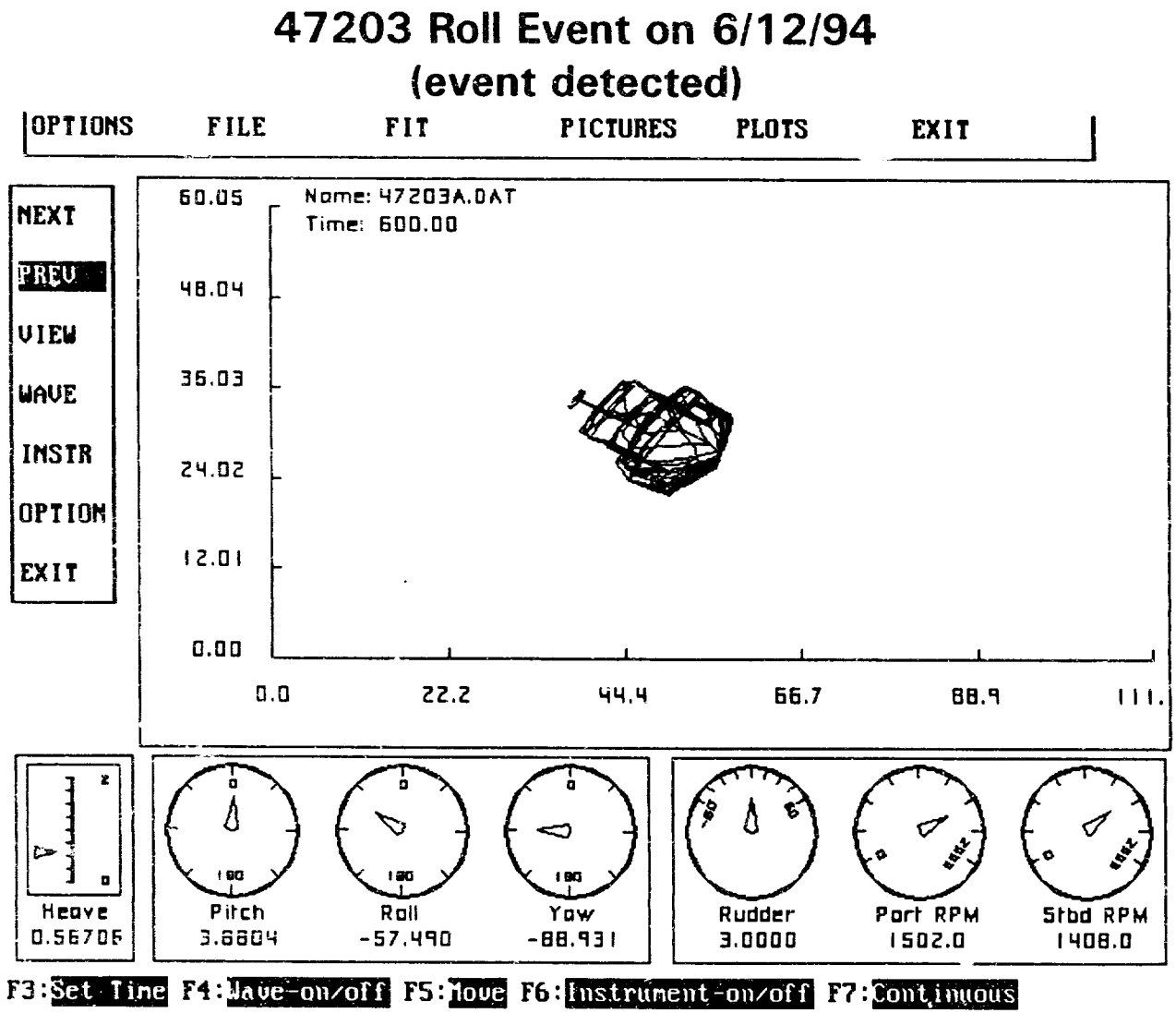
Figure C-17. 47203 Roll Event (-10 seconds)

47203 Roll Event on 6/12/94
(-4 seconds)



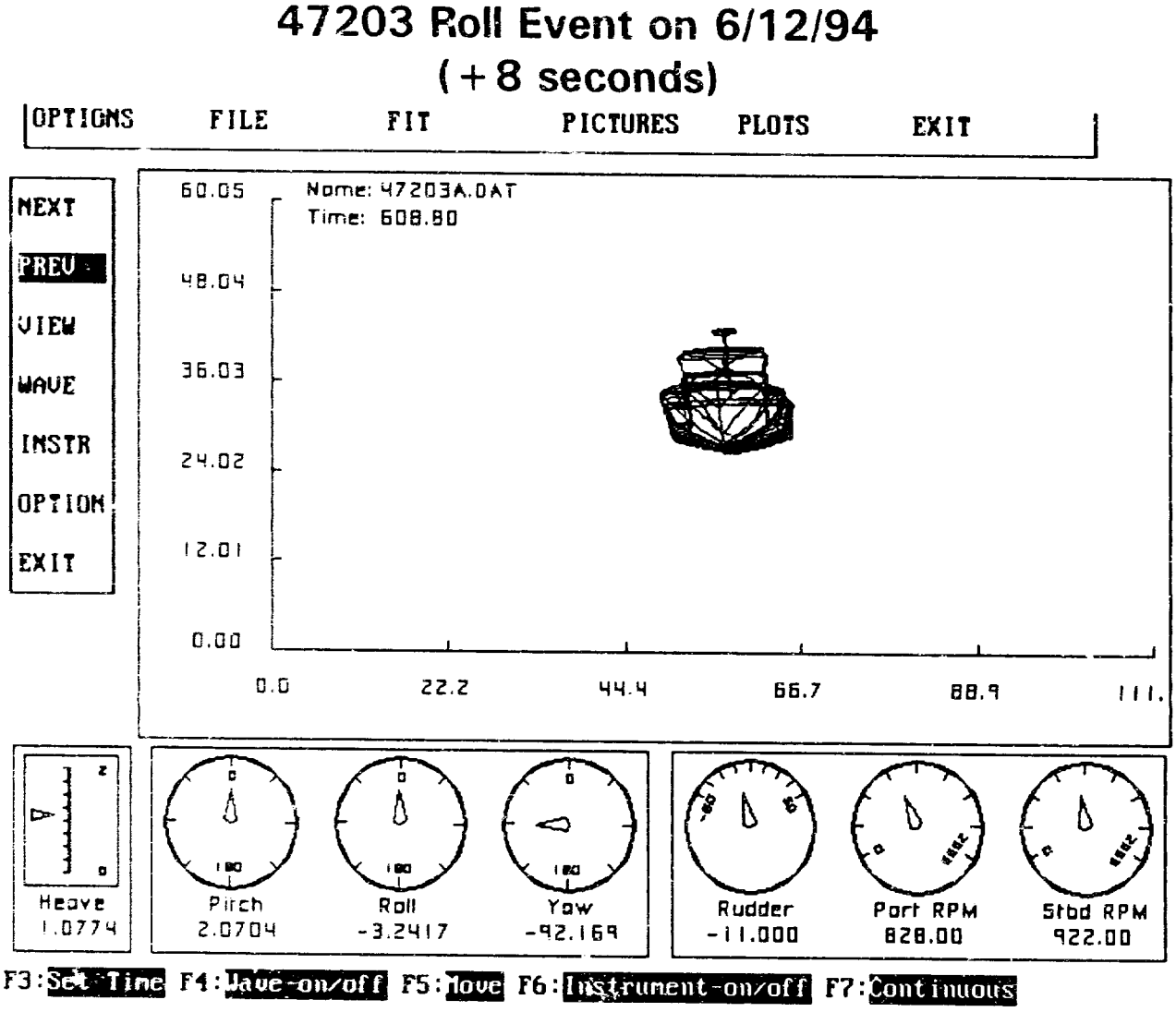
At 4 seconds before the event the 47203 is near clutch speed. The 47203 begins the roll to the 72 degree maximum roll recorded. At this point the 47203 begins to yaw rapidly.

Figure C-18. 47203 Roll Event (-4 seconds)



At the time of event detection (roll threshold was set to 60 degrees) the engine RPM increases rapidly. The rudder goes to amidship during the event sequence.

Figure C-19. 47203 Roll Event (Event Detected)



At 8 seconds after the event the 47203 is again near clutch speed. The rudder direction is changing rapidly until it attains 30 degrees starboard approximately 15 seconds after the event detection.

Figure C-20. 47203 Roll Event (+8 seconds)

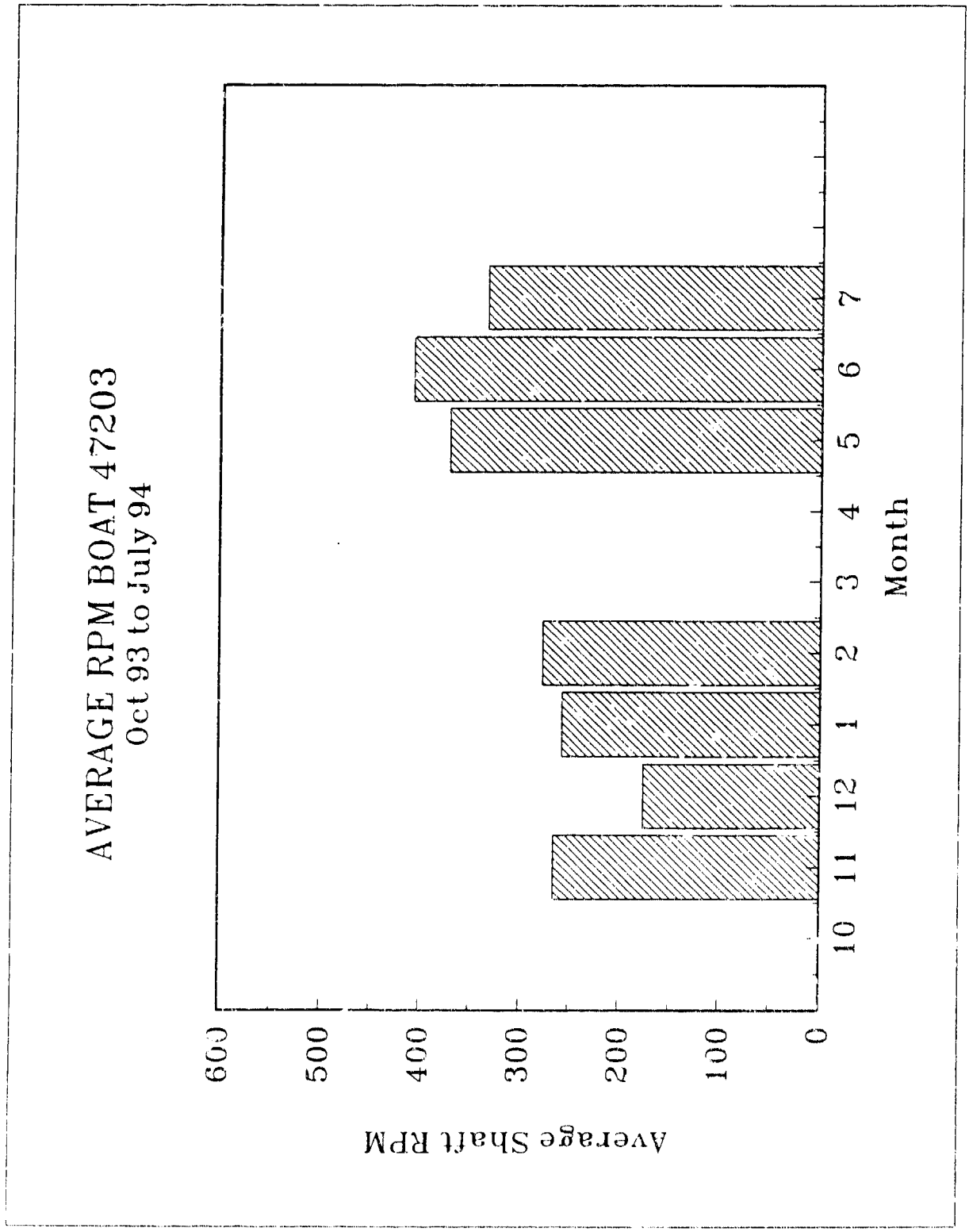


Figure C-21. 47203 Average RPM

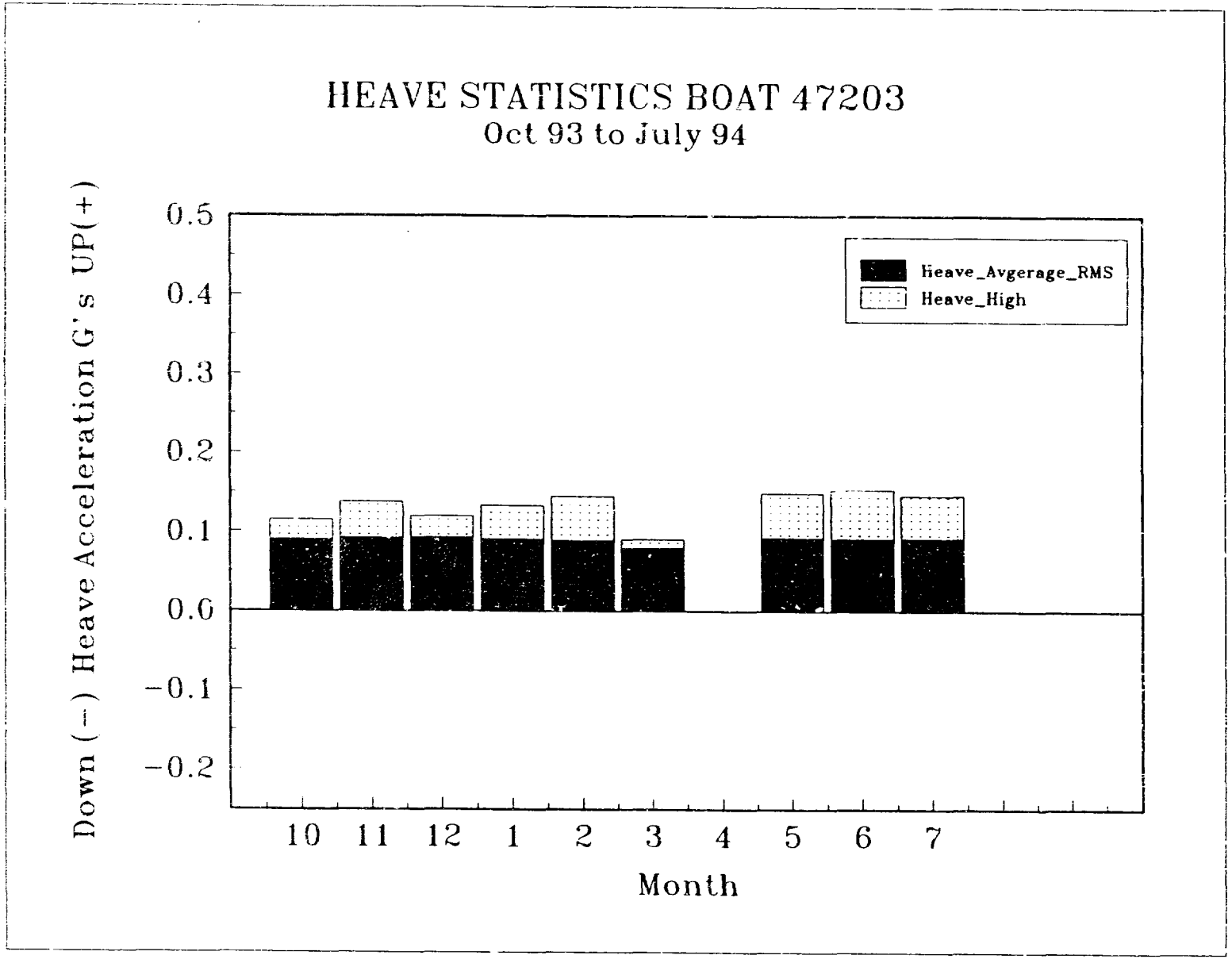


Figure C-22. 47203 Heave Statistics

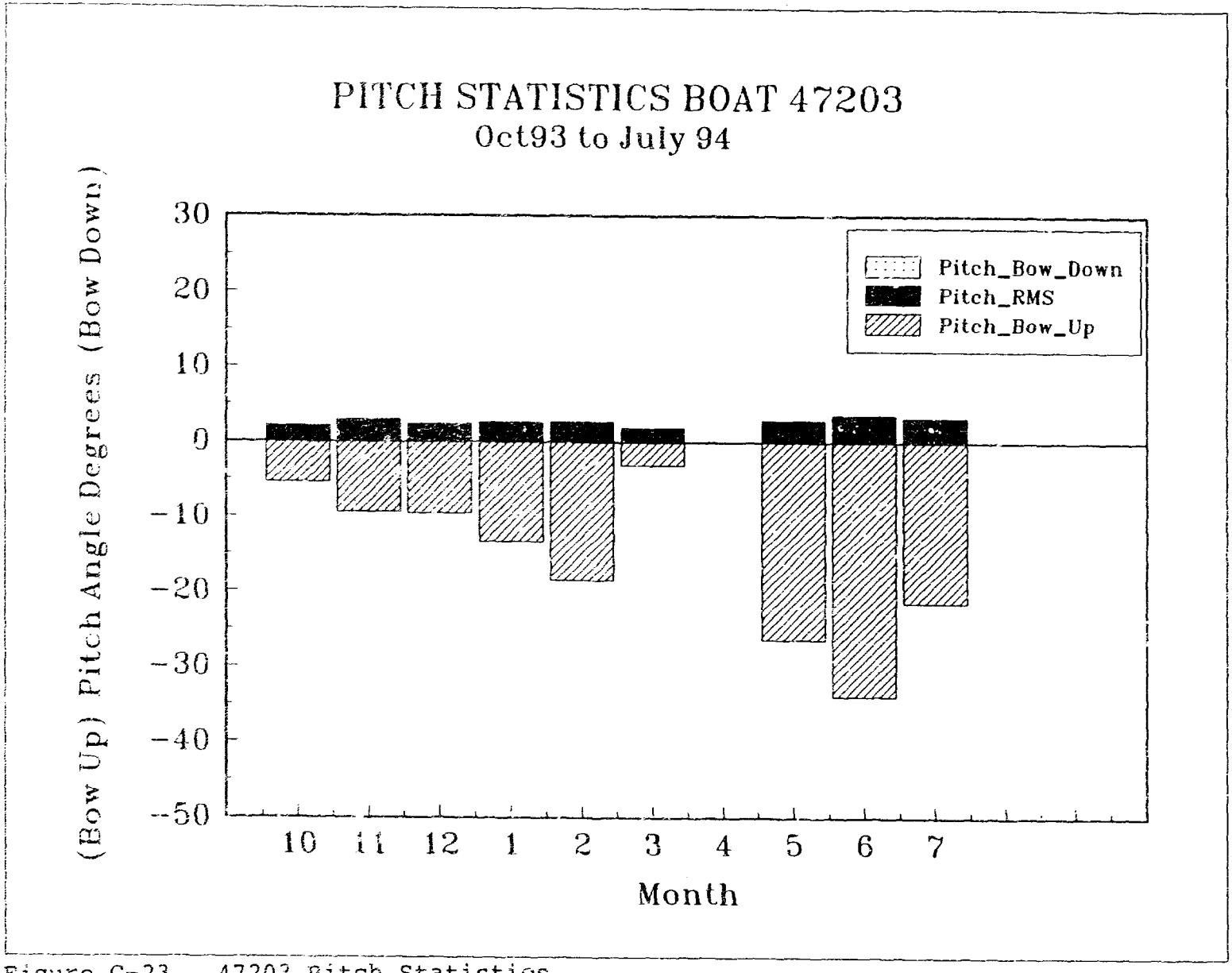


Figure C-23. 47203 Pitch Statistics

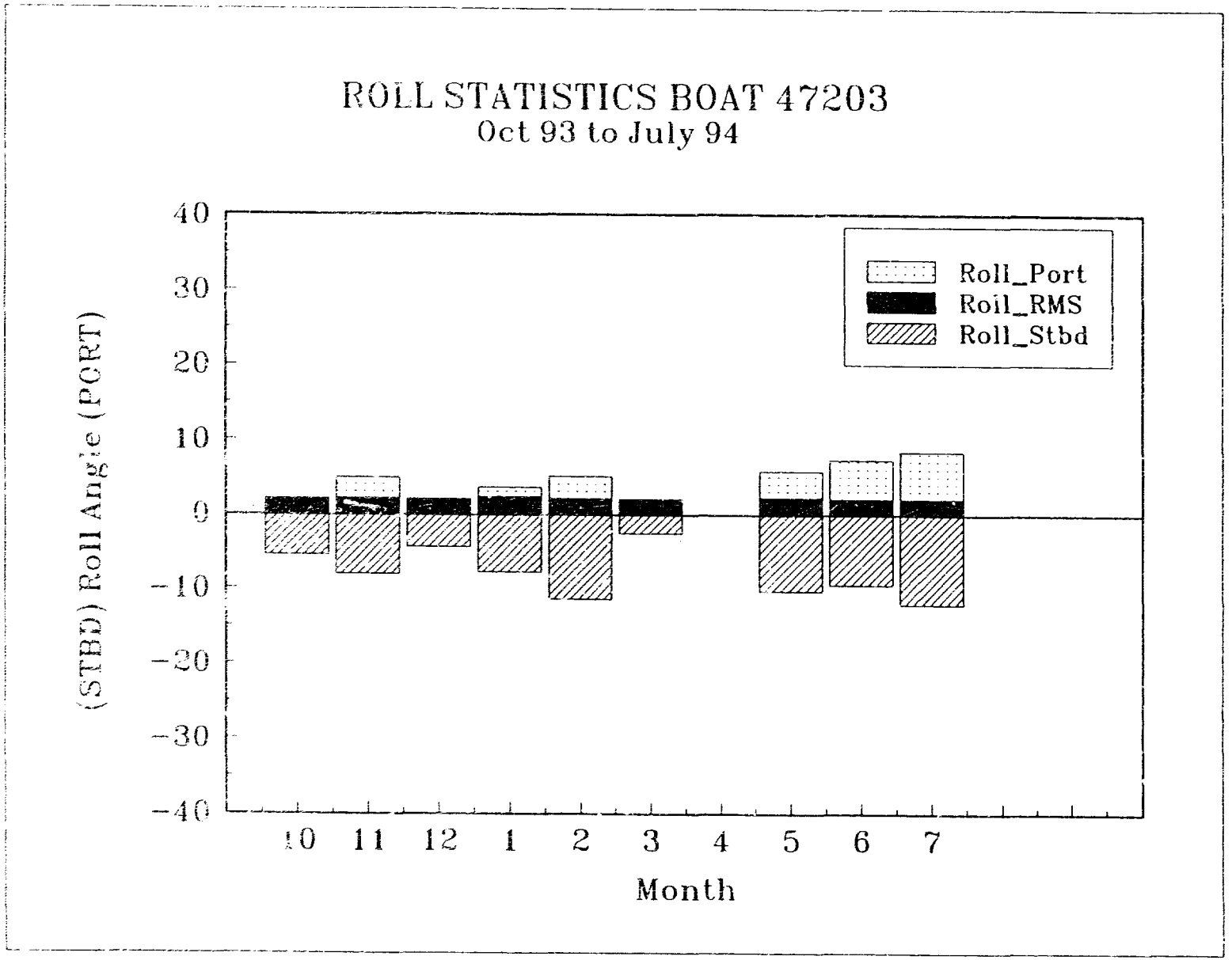


Figure C-24. 47203 Roll Statistics

APPENDIX D

47204 DATA RESULTS

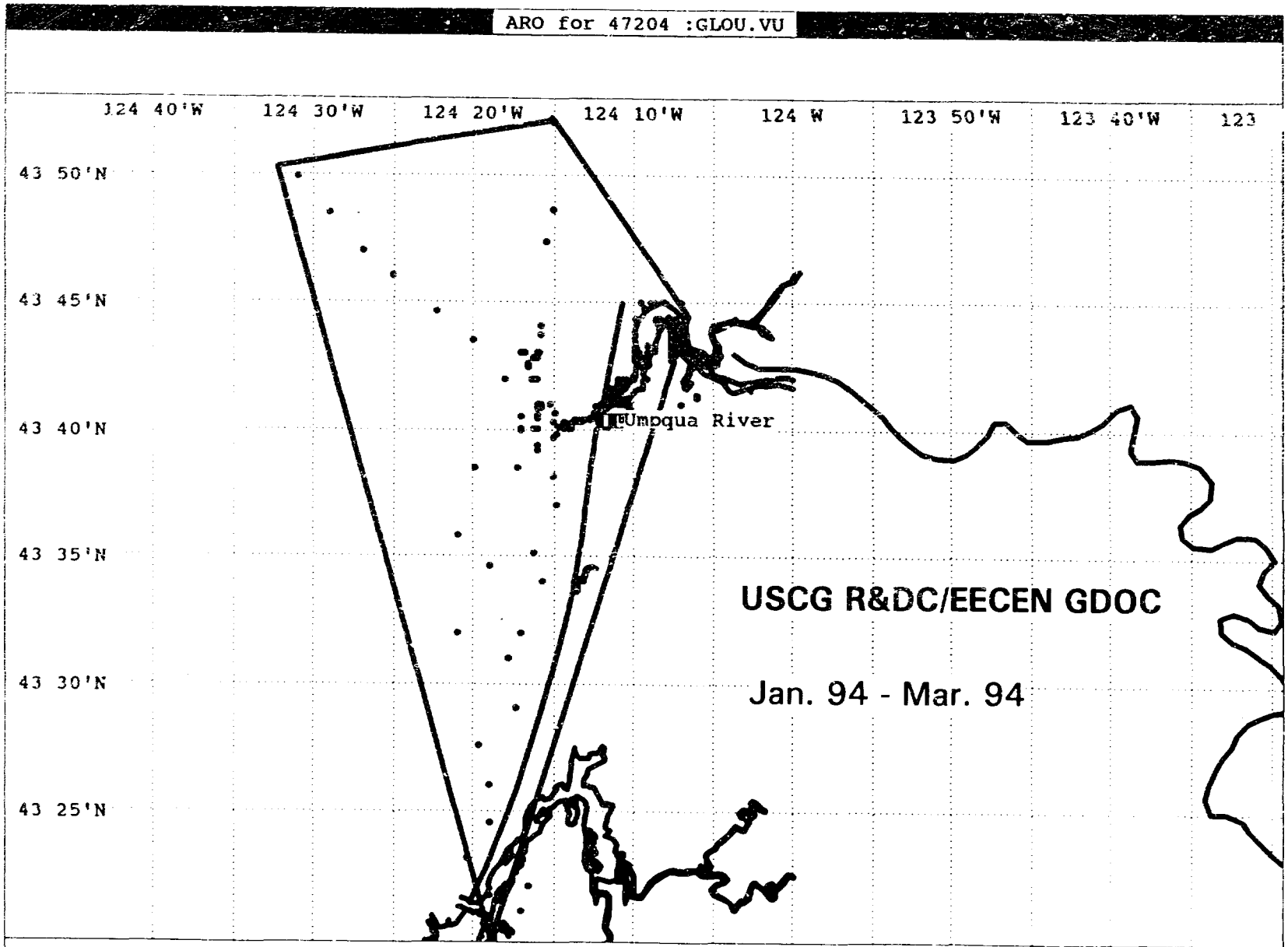


Figure D-1. Area of Recorded Operations for 47204

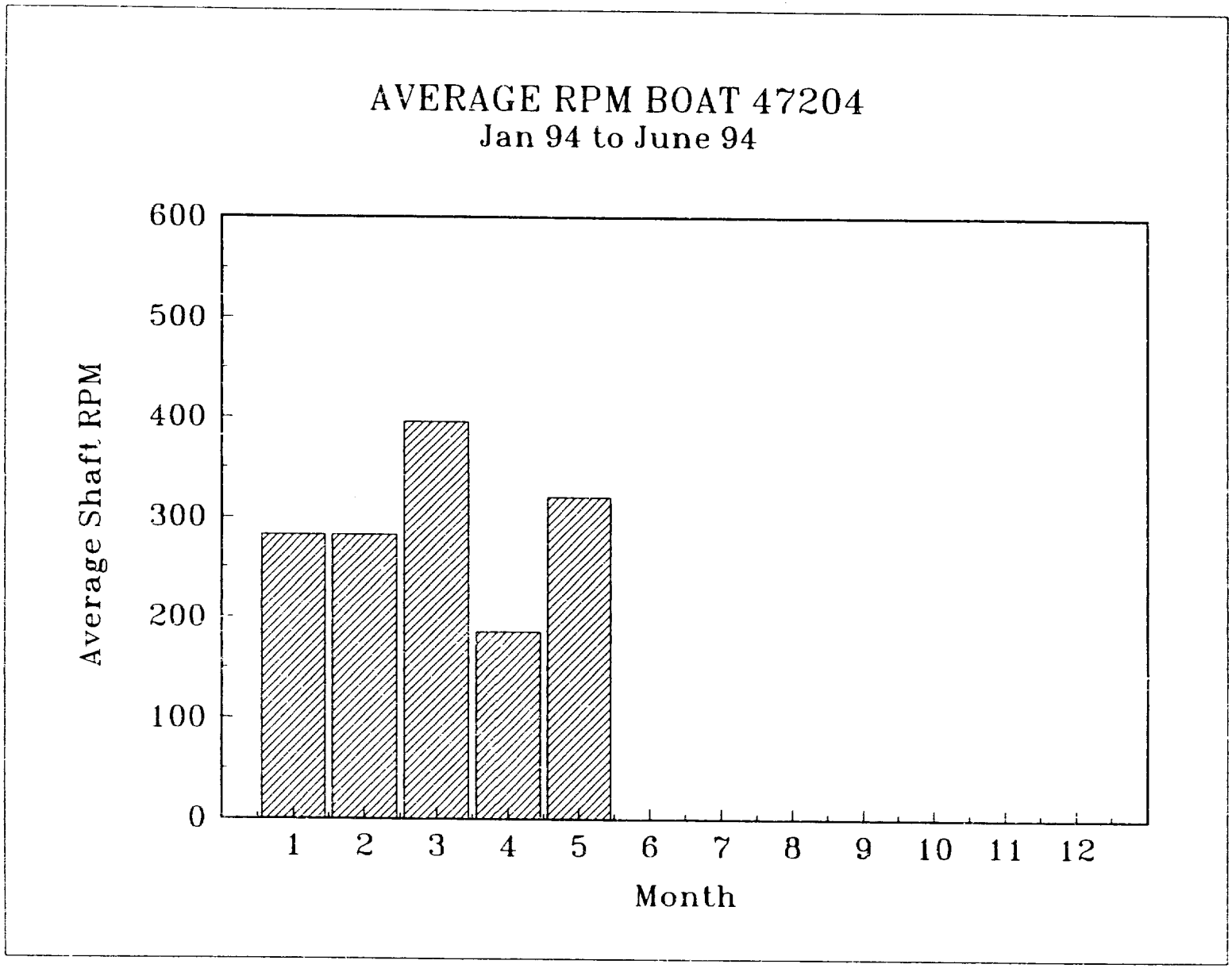


Figure D-2. 47204 Average RPM

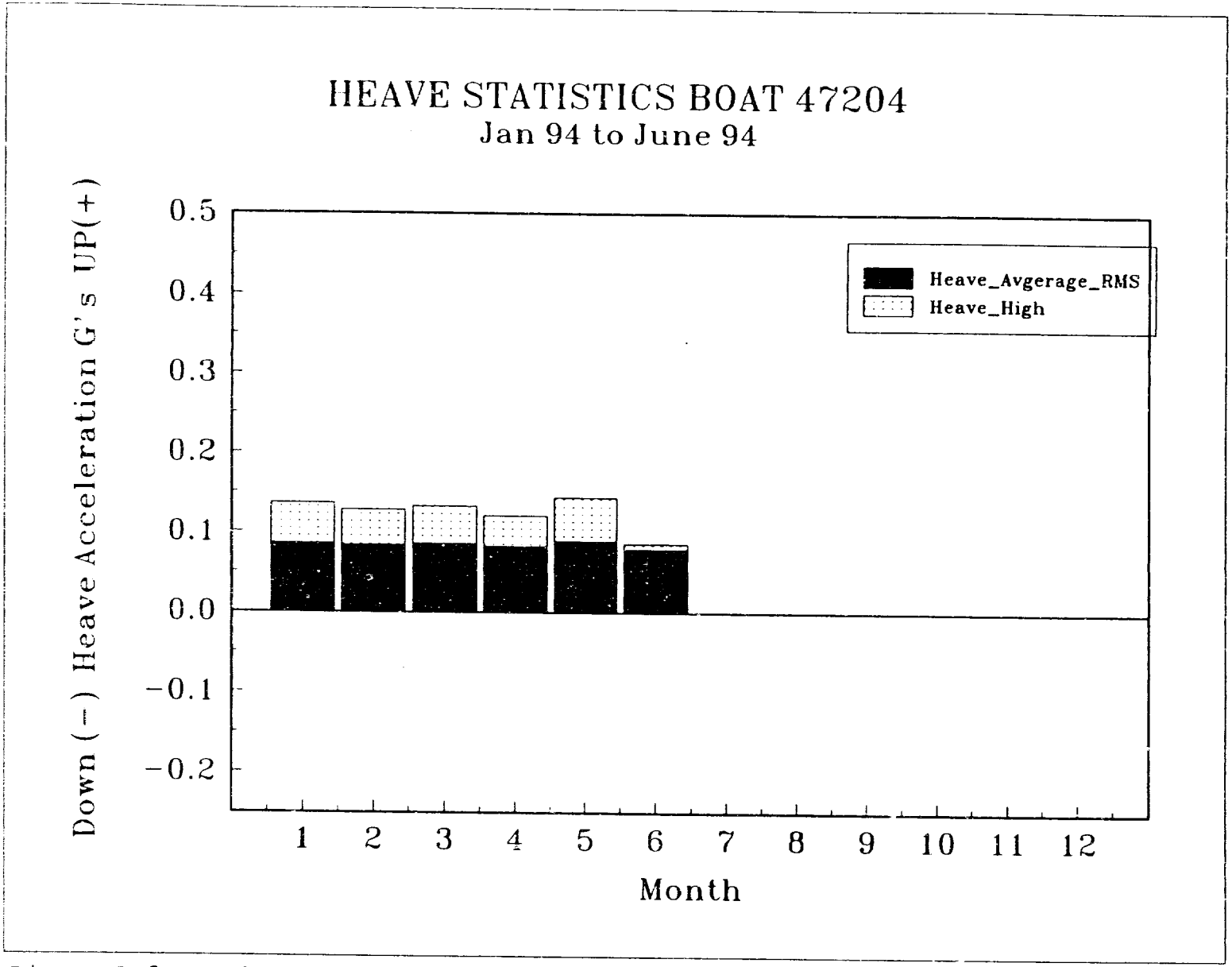


Figure D-3. 47204 Heave Statistics

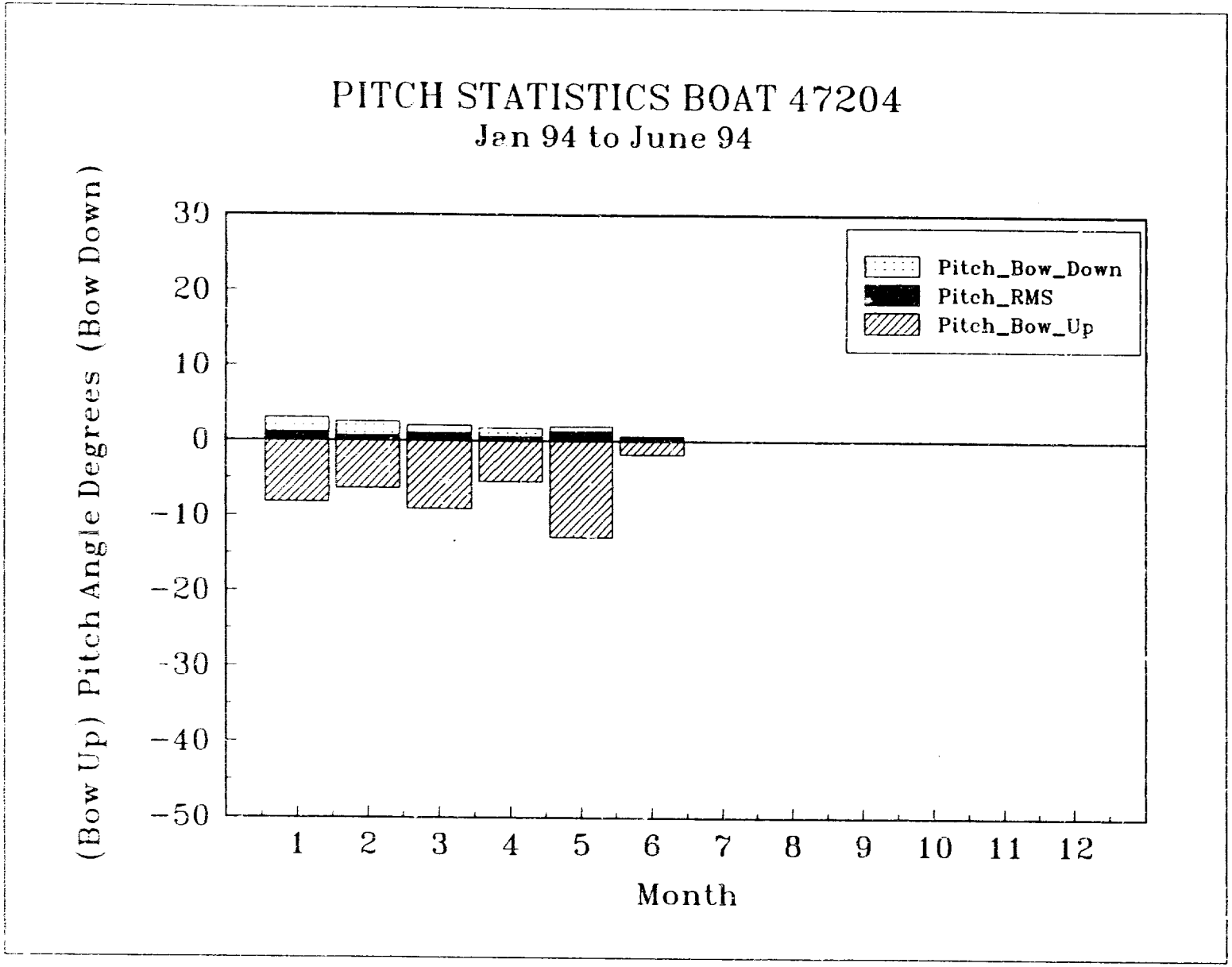


Figure D-4. 47204 Pitch Statistics

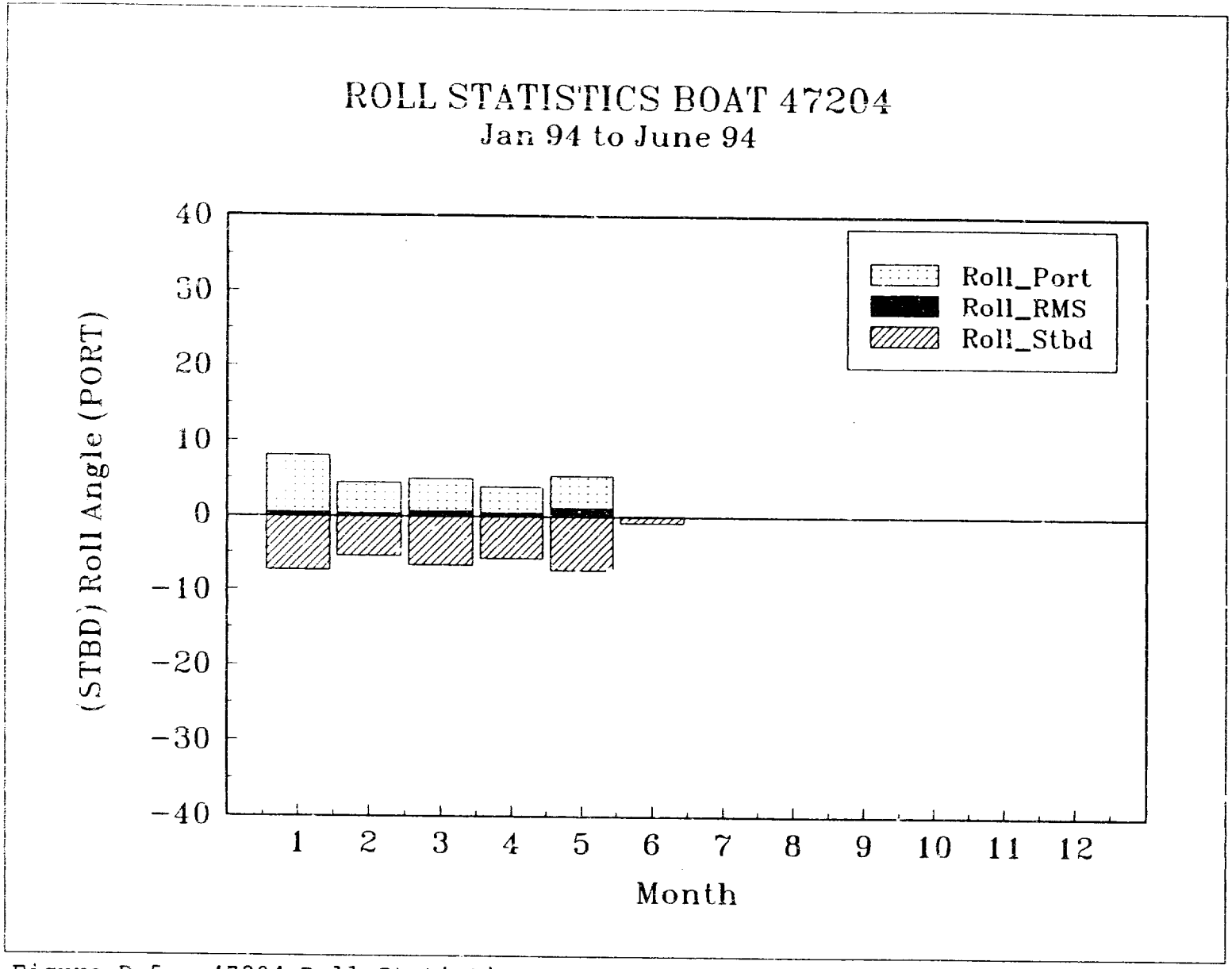


Figure D-5. 47204 Roll Statistics

APPENDIX E

47205 DATA RESULTS

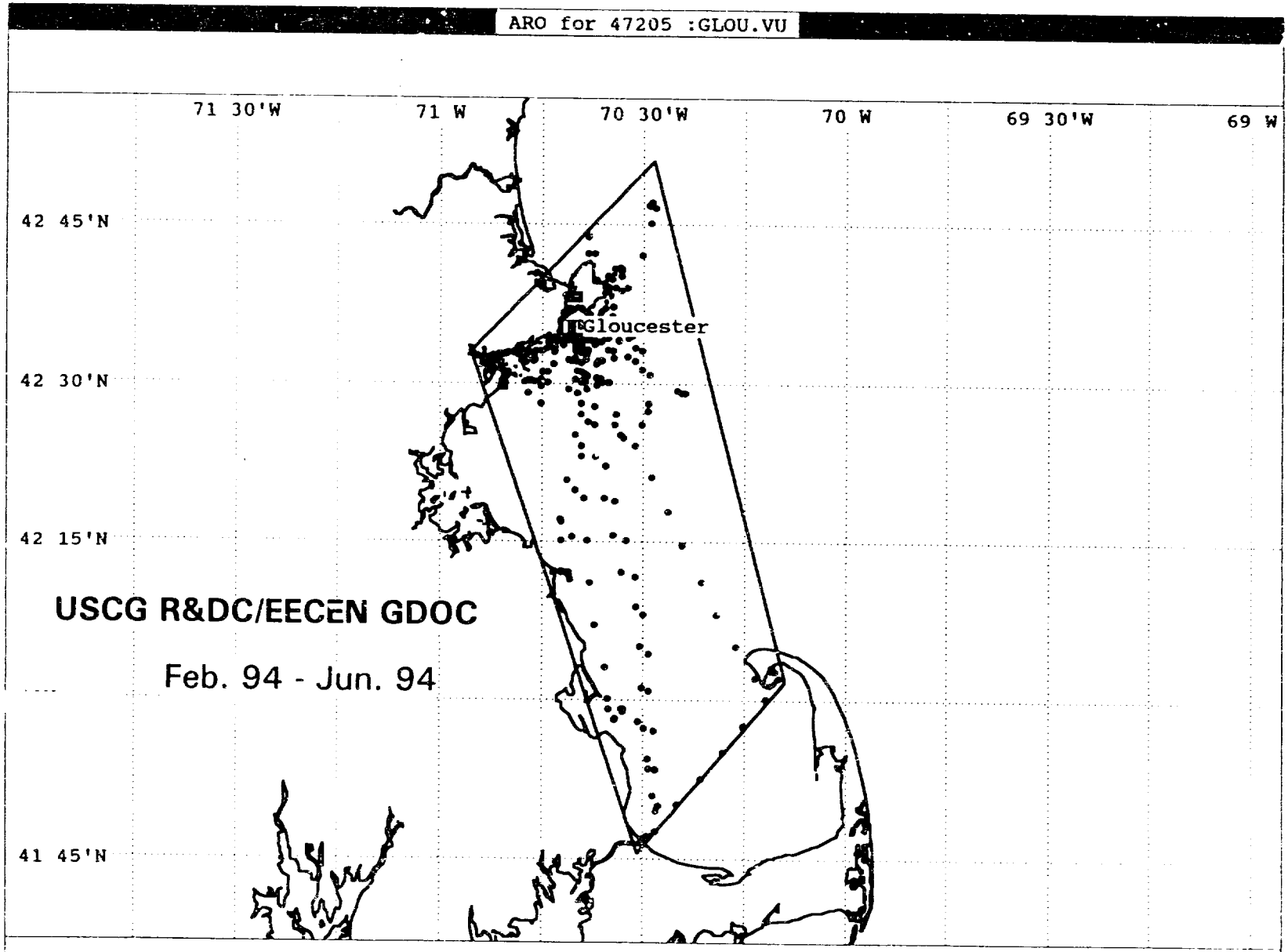


Figure E-1. Area of Recorded Operations for 47205

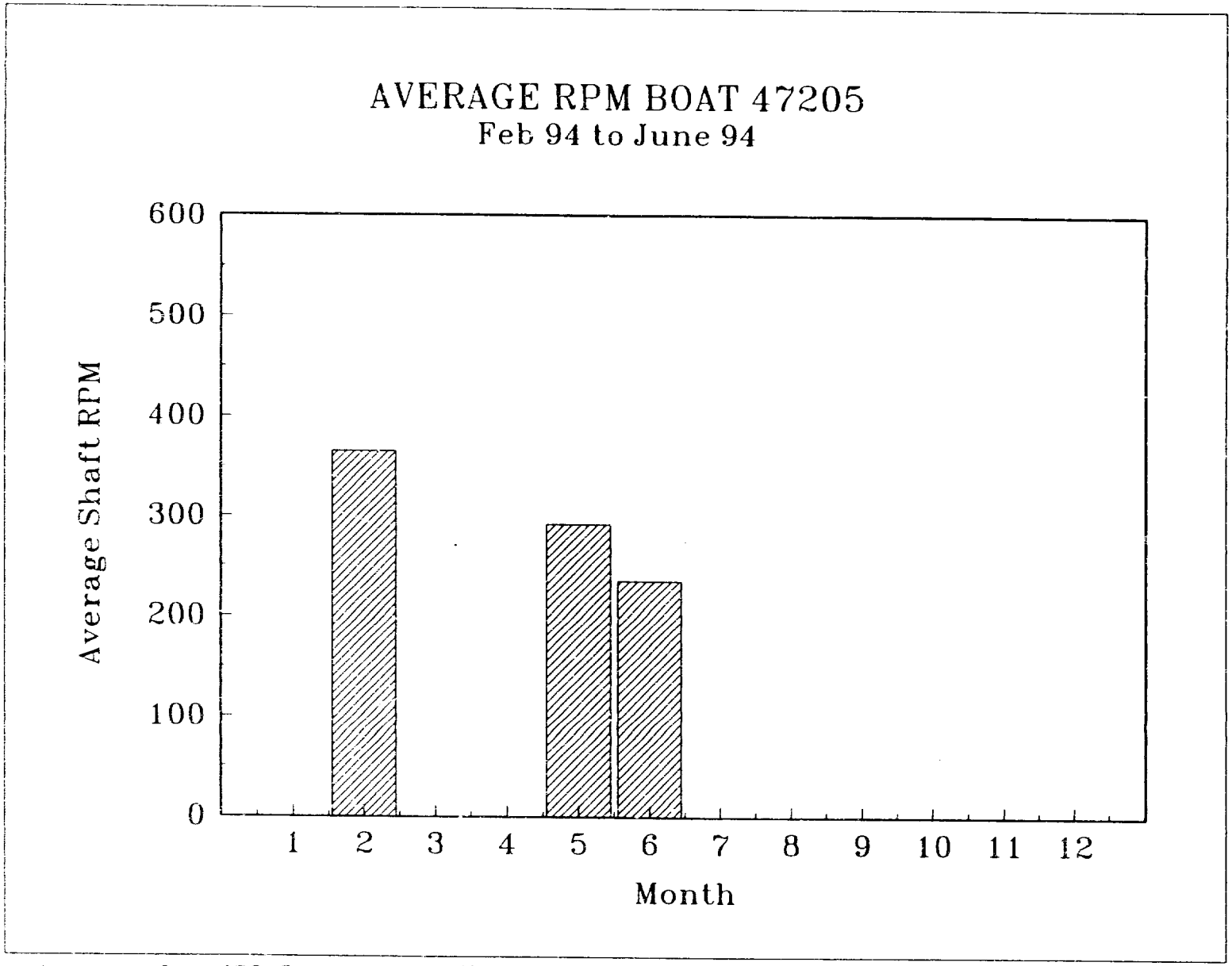


Figure E-2. 47205 Average RPM

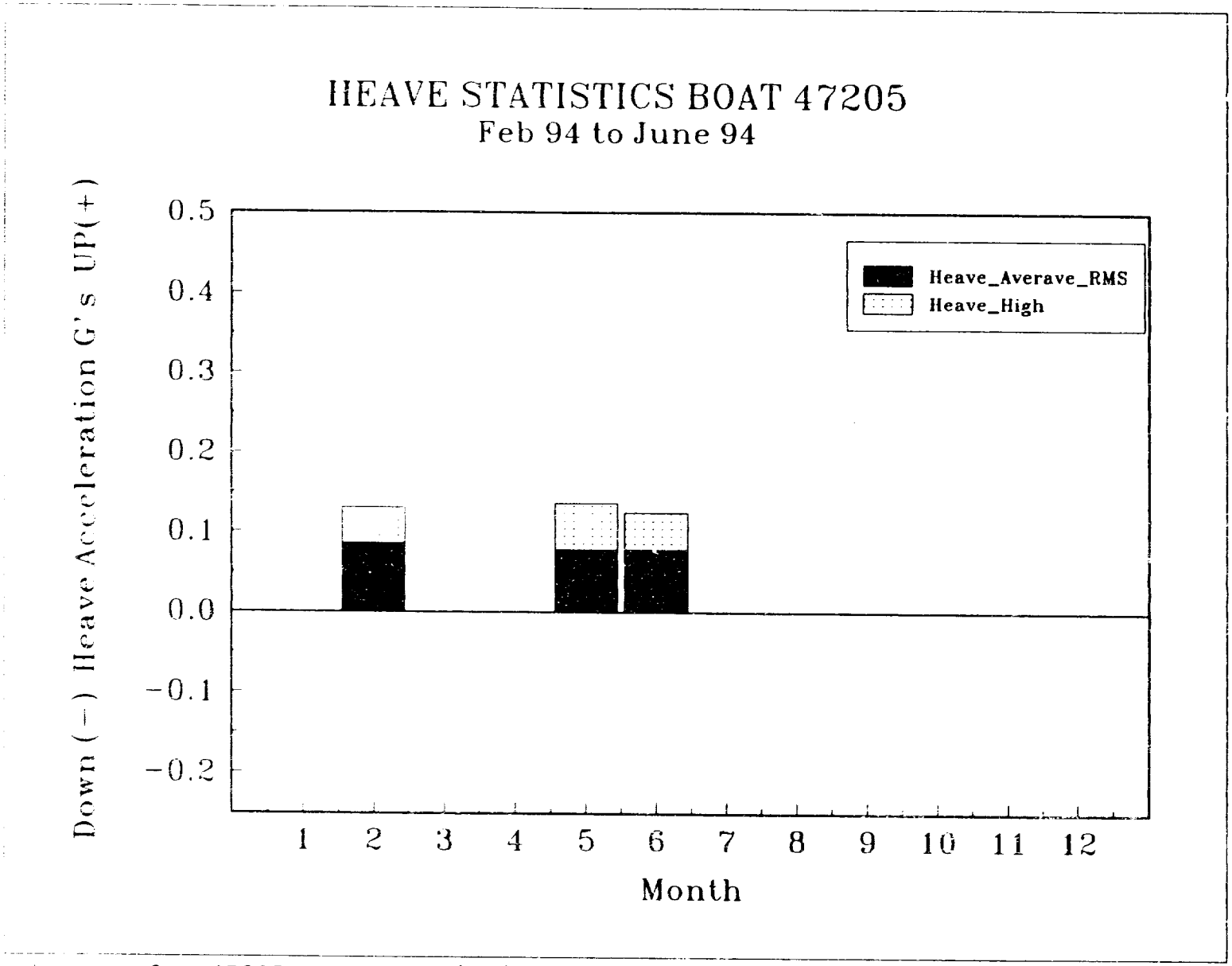


Figure E-3. 47205 Heave Statistics

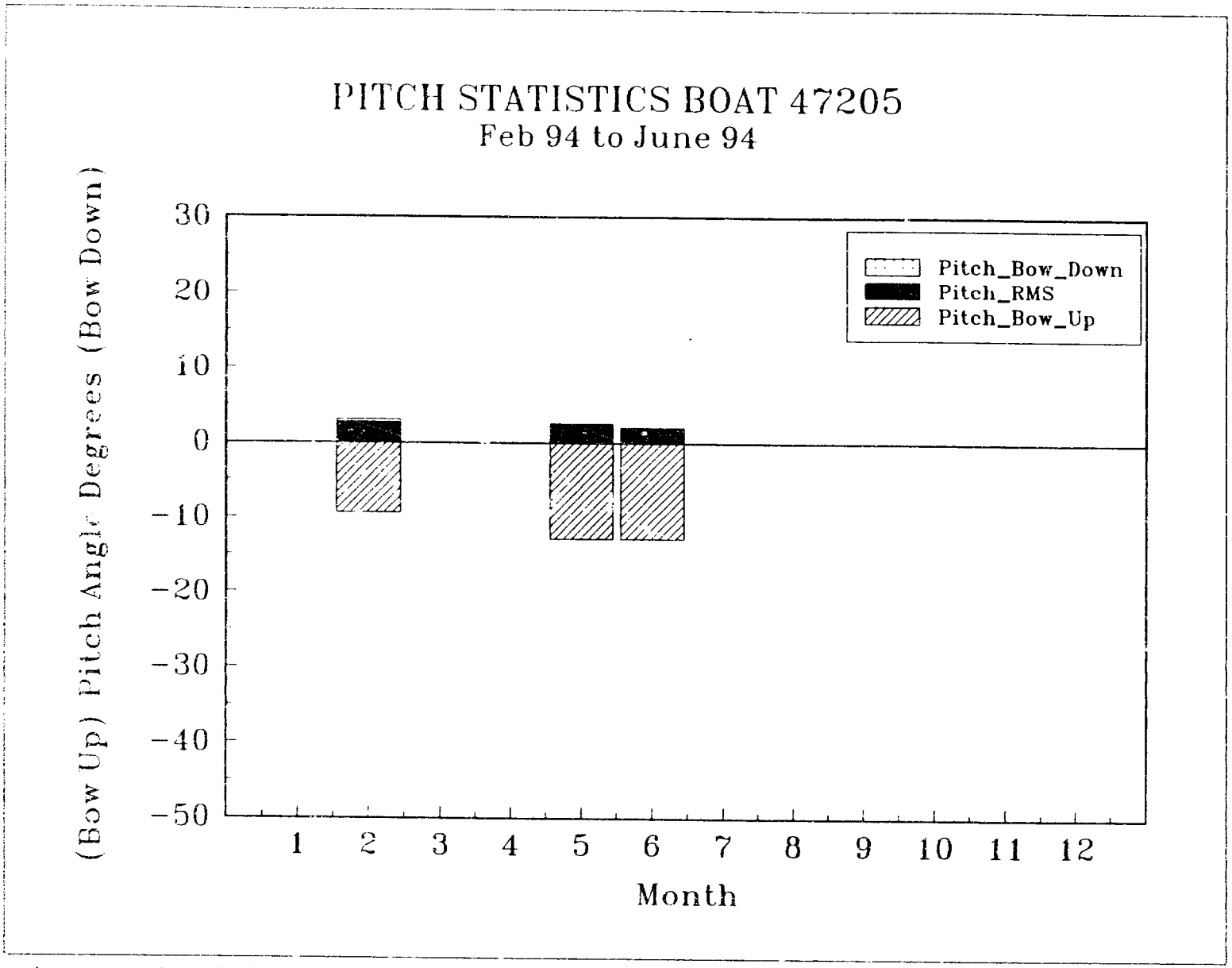


Figure E-4. 47205 Pitch Statistics

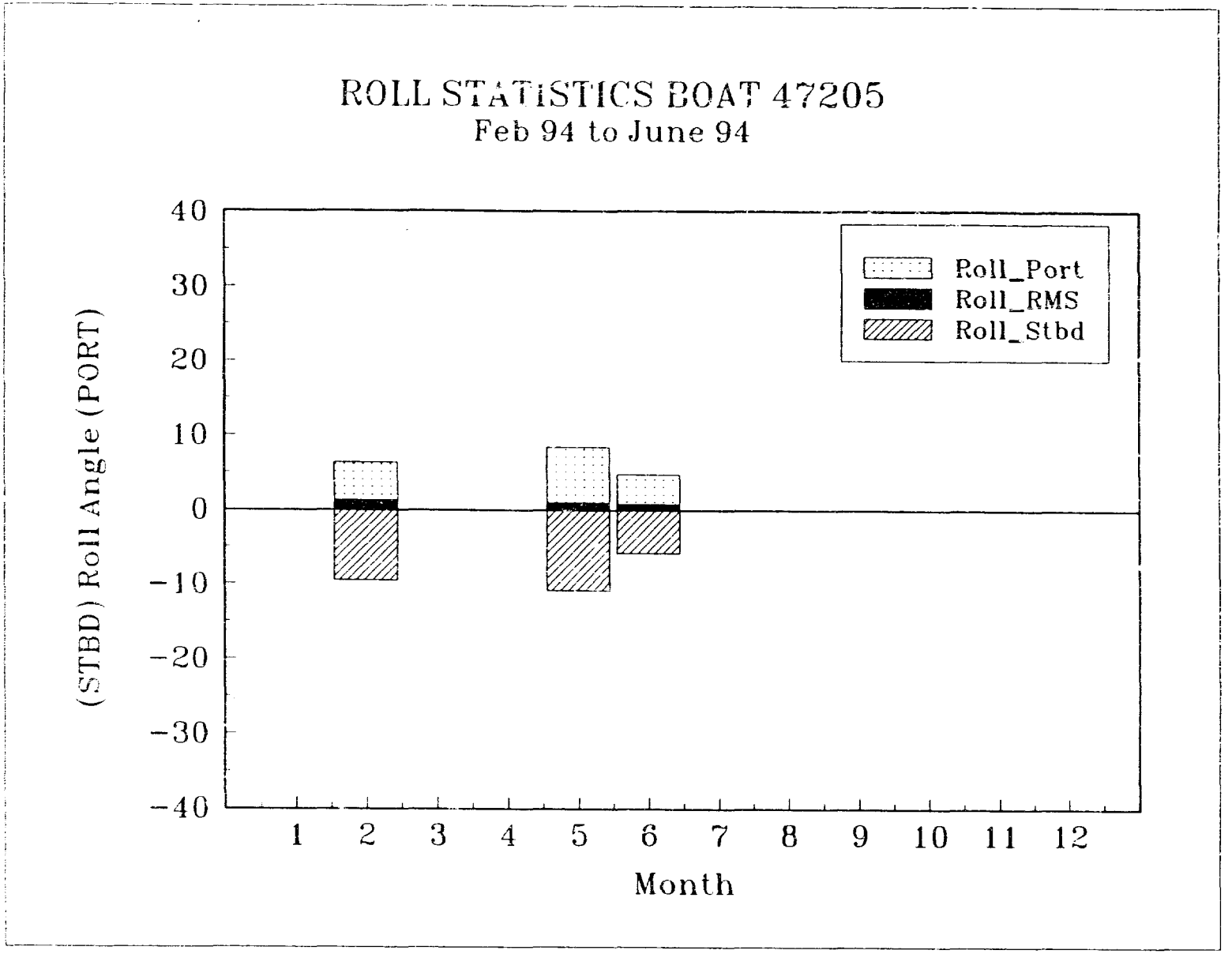


Figure E-5. 47205 Roll Statistics

APPENDIX F

47200 DATA RESULTS

(Data was not collected on the 47200
during this phase of the evaluation)

APPENDIX G

LIST OF HARDWARE AND SOFTWARE

MDR MAJOR PARTS LIST

1. Container for Mission Data Recorder -- Hoffman Enclosure part # A-1287JFGQR 57.65.

2. Computer/Data Acquisition System -- Tattletale Model 5 Computer with 2-Meg RAM board from Onset Computer Corp., PO Box 3450, Pocasset, MA 02559-3450, 508-563-9000.

3. Yaw Angle Sensor -- KVH model C100 Compass Engine Part # 54-0044 KVH Industries, Inc., 110 Enterprise Center, Middletown, RI 02840, (401) 847-3327.

4. Roll & Pitch Angle Sensor -- Humphrey model CP17-0601-1 Pendulum sensor. Humphrey Inc., 9212 Balboa Avenue, San Diego, CA 92123, (619) 565-6631.

5. Vertical Acceleration Sensor -- +/-4G Accelerometer model 141. Setra Systems Inc., 45 Nagog Park, Acton, MA 01720, (508) 263-1400.

6. Rudder Angle Sensor -- two manufacturers:

   a. Magnetek Position transducer model # PSA-40A-5K(A179) from Magnetek, 650 Easy Street, Simi Valley, CA 93065, (805) 581-3985.

   b. CELESCO Position Transducer, Model # PT8101-0040-111-3110 from Celesco Transducer Products, Inc., 7800 Deering Avenue, PO Box 7964, Canoga Park, CA 91309-7964, (818) 884-6860.

7. RPM Pick Up Sensor -- BANNER Model Q19SN6LP Polarized Retro Sensor. From Banner Engineering Corp., 9714 10th Avenue No., Minneapolis, MN 55441, (612) 544-3164.

8. Battery -- 12V, 6Ah Part # JC1260, from Johnson Controls.

9. Battery Charger -- 12V 250mA Type GRC12250CDF from Johnson Controls.

MDR Software

1. TTBASIC MDR Program

Data Reduction Software

1. BOATVU developed by GESAC, Inc., for Coast Guard R & D Center.
2. GDOC developed by CG DECEN.
3. MATLAB, The Math Works, Inc.
4. AXUM, TriMetrix, Inc.